NASA CONTRACTOR REPORT

NASA CR-2082

FOUR-DIMENSIONAL WORLD-WIDE ATMOSPHERIC MODELS (SURFACE TO 25 km ALTITUDE)

by David B. Spiegler and Mary G. Fowler

Prepared by
ALLIED RESEARCH ASSOCIATES, INC.
Baltimore, Md. 21203
for George C. Marshall Space Flight Center

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • JULY 1972

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
NASA CR-2082		
4. TITLE AND SUBTITLE FOUR-DIMENSIONAL WORLD-WIDE ATMOSPHERIC MODELS (Surface to 25 Km Altitude)		5. REPORT DATE July 1972 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) David B. Spiegler and Mary G. Fowler		8. PERFORMING ORGANIZATION REPORT # 9G-88F
9. PERFORMING ORGANIZATION NAME AND ADDRESS Allied Research Associates, Inc. P. O. Box 536 Baltimore, Maryland 21203		10. WORK UNIT NO. 11. CONTRACT OR GRANT NO. NAS8-26928
12. SPONSORING AGENCY NAME AND ADDRESS NASA Washington, D. C.		13. TYPE OF REPORT & PERIOD COVERED CONTRACTOR REPORT 14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

Four-dimensional atmospheric models previously developed for use as input to atmospheric attenuation models are evaluated to determine where refinements are warranted. The models are refined where appropriate. A computerized technique is developed that has the unique capability of extracting mean monthly and daily variance profiles of moisture, temperature, density and pressure at 1 km intervals to the height of 25 km for any location on the globe. This capability could be very useful to planners of remote sensing of earth resources missions in that the profiles may be used as input to the attenuation models that predict the expected degradation of the sensor data. Recommendations are given for procedures to use the four-dimensional models in computer mission simulations and for the approach to combining the information provided by the 4-D models with that given by the global could models.

17. KEY WORDS	18. DISTRIBUTION STATEMENT		

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
Unclassified	Unclassified	72	$3.00

*For sale by the National Technical Information Service, Springfield, Virginia 22151

FOREWORD

The objective of the four-dimensional atmospheric modeling task is to provide world-wide profiles of pressure, temperature, density, and moisture from the surface to 25 km altitude. The model gives mean monthly values and daily variations of the four parameters for any input of latitude, longitude, and month. This model can then serve as input for attenuation models that predict the degree of atmospheric attenuation likely to be encountered by satellite or air-borne electromagnetic sensors engaged in earth resources observations. It can also be used as mean model atmospheres in trajectory and vehicle heating analyses. The 4-D computer program can be obtained, upon request, from the Aerospace Environment Division, NASA-Marshall Space Flight Center, Alabama 35812.

Associated work has been and is still being done in this field. For example, work reported on, thus far, includes the world-wide cloud cover model (NASA CR 61226 and NASA CR 61345), and the interaction model involving microwave energy and atmospheric variables (NASA CR 61348). The four-dimensional atmospheric model is being improved to ultimately present pressure, temperature, density, moisture, and cloud cover as one attenuation model for earth resources problems.

ACKNOWLEDGMENTS

The research described in this report was performed by the Geophysics and Aerospace Division of Allied Research Associates, Inc. (ARA) under sponsorship of the George C. Marshall Space Flight Center, Aerospace Environment Division (AED) of the National Aeronautics and Space Administration, Contract No. NAS 8-26928. Our thanks to S. Clark Brown and Dale L. Johnson of NASA (AED) for their participation in technical discussions of value to the study.

The northern and southern hemisphere monthly data on the 5° latitude-longitude grid and the northern hemisphere high-altitude daily data on the NMC grid were made available for use in this study by Dr. Harold Crutcher of the National Climatic Center and Roy Jenne of NCAR. Our thanks to Frank Lewis of the Techniques Development Laboratory, NOAA, for providing daily precipitable water data for the United States.

Paul E. Sherr, David T. Chang, James H. Willand, Robert F. Smiley, and C. James Bowley made contributions of value to this study.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

List of Illustrations (Continued)

LIST OF TABLES

1. INTRODUCTION

In a previous study Spiegler and Greaves (1971) developed techniques for obtaining mean monthly profiles and daily variances of moisture, temperature, density and pressure from the surface to 25 km for 36 homogeneous moisture regions over the globe. These four-dimensional (space, x, y, z, and time, t) models were developed to serve as input for atmospheric attenuation models that predict the degree of attenuation likely to be encountered by satellite or airborne observations. In addition, the 4-D models can also be used as mean model atmospheres in trajectory and vehicle heating analyses. With these applications in mind, a computer program was generated that provides appropriate regional mean profiles and daily variances of atmospheric parameters for any month of the year given the latitude, longtitude and month.

Some data limitations during the previous study necessitated the design of procedures to overcome the missing data and still meet the specified requirements. Thus, one of the tasks of this study was to analyze in more detail (than was possible previously) both the homogeneous region profiles and the individual data point profiles for both northern and southern hemispheres with the objectives of (1) identifying where refinements in the model profiles were warranted and (2) in those instances, refining the models through new or improved processing procedures and/or additional data.

Another major objective of this study was to develop a computerized method to extract a vertical profile of mean, monthly values and daily variances of moisture, temperature, pressure and density from the surface to 25 km for any given latitude, longitude and month (to eliminate the smoothing inherent in the homogeneous region concept).

Additional goals of this project were to:

- Develop techniques and procedures to use the 4-D models in conjunction with precipitable water data in computer mission simulations.

- Determine the feasibility of combining the 4-D atmospheric models with the cloud model (Greaves et al, 1971) to develop simulation programs that will permit prediction of both signal attenuation and cloud cover.

2. REFINEMENT OF THE 4-D ATMOSPHERIC MODELS

The previous 4-D atmospheric models report (Spiegler and Greaves, 1971) describes the concept of homogeneous moisture regions and the criteria for defining these regions over the globe. The criteria, repeated here for discussion purposes, is as follows:

- The annual average moisture
- The degree of seasonal change (of the total precipitable water).
- The degree of variability across the region
- The geographic location

After the regions were defined, techniques for determining moisture profiles for regions developed, and processing completed, time and resources permitted a random check between moisture profile data from the northern hemisphere regions as compared with profile data from the same (numbered) regions in the southern hemisphere for winter and summer seasons. (The seasonal reversal between hemispheres was accounted for throughout the study.) In general, this comparison revealed that the data compared very favorably between the same regions of each hemisphere. However, a more detailed comparative analysis was desirable to include all regions and all seasons and this was accomplished as part of this study. Again, for the most part, only minor differences existed between the northern hemisphere region profiles and the profiles from the same regions in the southern hemisphere as typified by the data shown in Tables 1 (a) through 1 (c).

However, for nine regions there were significant seasonal differences in the moisture and/or temperature profiles despite annual average moisture being very similar. Significant differences are defined as greater than or equal to 25% in the mean monthly absolute humidity at one or more levels with these differences apparent for more than one season. The nine southern hemisphere regions where the profile data differed significantly from the counterpart region in the northern hemisphere are Regions 1, 2, 6, 7, 15, 26, 30, 31, and 33. Nine region numbers

TABLE 1(a)

COMPARISONS OF NORTHERN AND SOUTHERN HEMISPHERE MEAN MOISTURE AND TEMPERATURE DATA SFC - 5 km

(Example of no significant differences)

REGION 12

Height (km)	Midseason Month	Mean Absolute Humidity ($g\ m^{-3}$)		Mean Temperature ^{o}K	
		N. H.	S. H.	N. H.	S. H.
SFC	January	10.66	10.01	290	289
	July	14.90	13.35	294	295
1	January	6.25	5.66	285	285
	July	8.90	8.08	292	290
2	January	3.78	2.78	280	280
	July	5.42	4.50	287	285
3	January	2.14	1.33	275	275
	July	3.07	2.46	283	281
4	January	1.33	.81	269	268
	July	1.97	1.45	277	275
5	January	.82	.52	263	262
	July	1.28	.85	270	270

TABLE 1(b)

COMPARISONS OF NORTHERN AND SOUTHERN HEMISPHERE MEAN MOISTURE AND TEMPERATURE DATA SFC - 5 km

(Example of no significant differences)

REGION 17

Height (km)	Midseason Month	Mean Absolute Humidity ($g\ m^{-3}$)		Mean Temperature °K	
		N. H.	S. H.	N. H.	S. H.
SFC	January	12.10	12.80	290	293
	July	19.72	17.08	299	298
1	January	7.36	7.93	284	287
	July	13.12	11.09	294	292
2	January	4.34	4.27	280	283
	July	8.26	6.44	288	288
3	January	2.49	2.34	276	277
	July	5.09	3.73	283	283
4	January	1.60	1.36	270	272
	July	3.21	2.29	277	277
5	January	1.02	.78	265	266
	July	2.00	1.40	271	271

TABLE 1(c)

COMPARISONS OF NORTHERN AND SOUTHERN HEMISPHERE MEAN MOISTURE AND TEMPERATURE DATA SFC - 5 km

(Example of no significant differences)

REGION 21

Height (km)	Midseason Month	Mean Absolute Humidity (g m^{-3})		Mean Temperature °K	
		N. H.	S. H.	N. H.	S. H.
SFC	January	16.21	17.27	296	298
	July	21.45	19.18	301	299
1	January	10.25	10.83	290	292
	July	14.57	12.59	298	293
2	January	6.08	6.15	286	287
	July	9.24	7.89	290	289
3	January	3.54	3.51	281	282
	July	5.82	4.85	284	284
4	January	2.17	2.12	276	277
	July	3.84	3.09	278	278
5	January	1.31	1.28	270	271
	July	2.51	1.96	272	272

were added to account for separate regional profiles for the southern hemisphere regions, making a total of 45 homogeneous regions for the globe. Regional profiles for the original regions that contained combined data from both hemispheres are necessarily changed by the separation of the previously merged data. (i.e., Regions 1, 2, 6, 7, 15, 26, 30, 31, and 33 now appear only in the northern hemisphere and profiles for these regions were recomputed using northern hemisphere data only.

Table 2 describes the characteristics for the nine new regions. Numbers in parentheses are the "old" region numbers. Figure 1 is a depiction of the 45 homogeneous moisture regions. Three ("old" southern hemisphere) regions (1, 2 and 6) are in Antarctic and Polar ocean areas where corresponding northern hemisphere regions have lower winter and higher summer moisture amounts. Table 3(a) contains profile data to 5 km for Region 1 (northern hemisphere and "old" southern hemisphere). The differences that are apparent represent a typical example of the kinds of differences also found in Regions 2 and 6 (not shown). Another three of the regions comprise the Australian desert and its adjacent areas, where moisture and temperature are significantly lower than corresponding desert and desert border regions in the northern hemisphere. Table 3 (c) shows the profile data for Region 30 (desert). Similar data profiles exist for the desert border regions.

The remaining three regions cannot be categorized into a group. Region 7 is described as "high midlatitude continent." In the northern hemisphere it represents rather large areas, but in the southern hemisphere, it covers only a limited region of South America. Table 3 (b) shows the differences in the data profiles for Region 7 for the two hemispheres. The maritime influence dominates the southern third of South America and is very likely the reason for the warmer, wetter winter and cooler, drier summer than in the high midlatitude continental regions of the northern hemisphere.

Although the annual average moisture for both southern and northern hemisphere Region 15 is very similar, the similarity comes about through the averaging of large moisture amounts in the northern hemisphere region in summer with

TABLE 2

CHARACTERISTICS OF THE NINE ADDITIONAL HOMOGENEOUS MOISTURE REGIONS

Region	Average Annual Moisture	Seasonal Change	Variability Across Region	Location	Remarks
37(1)	Very low	Very small	Small	Antarctic continent	Higher annual average moisture than arctic N. H. (Region 1) except lower in summer.
38(2)	Very low	Very small	Small	Northern Antarctic Ocean	Higher annual average moisture than subarctic and arctic continent N. H. (Region 2) winter and spring; lower in summer.
39(6)	Low	Very small	Small	S. H. polar ocean	Higher annual average moisture than N. H. polar oceans (Region 6) except in summer.
40(7)	Low-to-moderate	Very small	Very small	Southern one-third South America	Lower annual average moisture than high midlatitude continent (Region 7), except in winter.
41(15)	Moderate	Small-to-moderate	Small	S. H. lower midlatitude oceans.	
42(26)	Low-to-moderate	Small-to-moderate	Small-to-moderate	S. H. mountain ranges.	
43(30)	Low	Very small	Small	Australian Desert	Moisture lower than average of N. H. deserts (Region 30) in summer.
44(31)	Low	Small	Small	Border of Australian Desert.	Temperature much lower than N. H. border of desert (Region 31).
45(33)	Low-to-moderate	Moderate	Moderate except large in fall.	Tropical border of Australian Desert.	Lower moisture than N. H. tropical and equatorial desert borders (Region 33).

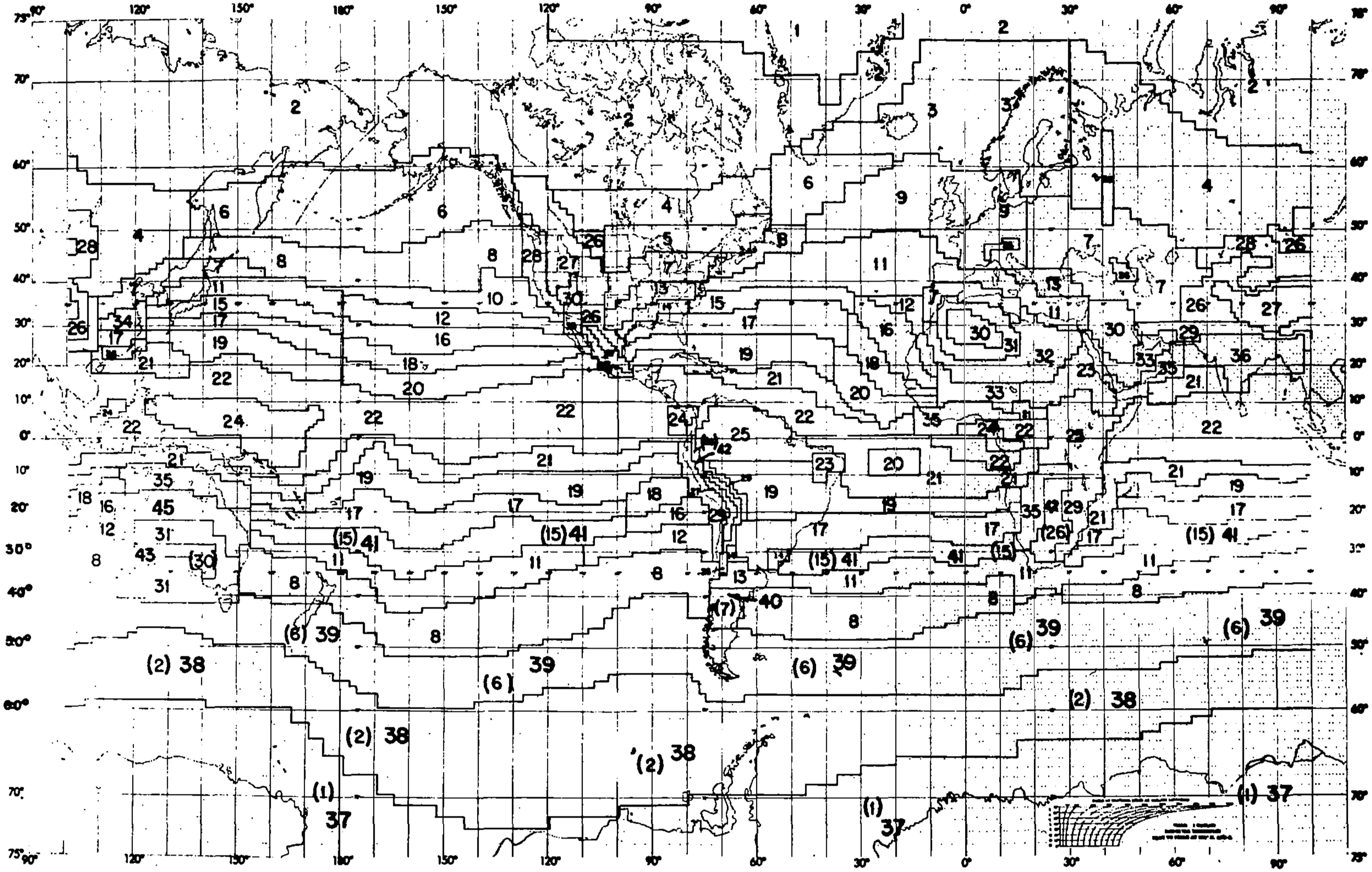


Figure 1. Homogeneous Moisture Regions

TABLE 3 (a)

COMPARISONS OF NORTHERN AND SOUTHERN HEMISPHERE MEAN MOISTURE AND TEMPERATURE DATA SFC - 5 km

(Example of significant differences)

REGION 1

Height (km)	Midseason Month*	Mean Absolute Humidity ($g\ m^{-3}$) N. H.	Mean Absolute Humidity ($g\ m^{-3}$) (old) S. H.	Mean Temperature °K N. H.	Mean Temperature °K (old) S. H.
SFC	January	.26	1.19	248	255
	April	.63	1.87	254	263
	July	4.84	3.31	275	271
	October	1.05	1.87	260	263
1	January	.41	.60	247	251
	April	.67	.84	253	254
	July	3.64	1.77	274	264
	October	1.03	.84	256	254
2	January	.29	.37	244	244
	April	.45	.48	250	247
	July	2.33	1.03	269	257
	October	.67	.48	253	247
3	January	.21	.24	241	236
	April	.31	.27	247	239
	July	1.47	.60	264	251
	October	.45	.27	249	239
4	January	.15	.15	237	230
	April	.20	.17	242	233
	July	.87	.34	259	245
	October	.27	.17	244	233
5	January	.15	.10	233	225
	April	.12	.20	237	228
	July	.50	.20	253	240
	October	.16	.20	239	228

*Keyed to Northern Hemisphere

TABLE 3(b)

COMPARISONS OF NORTHERN AND SOUTHERN HEMISPHERE MEAN MOISTURE AND TEMPERATURE DATA SFC - 5 km

(Example of significant differences)

REGION 7

Height (km)	Midseason Month*	Mean Absolute Humidity (g m^{-3})		Mean Temperature ^{o}K	
		N. H.	(old) S. H.	N. H.	(old) S. H.
SFC	January	3.67	5.10	272	279
	April	6.43	6.25	285	286
	July	13.68	7.70	297	290
	October	7.94	7.25	287	286
1	January	2.89	3.65	270	276
	April	4.66	4.27	280	281
	July	9.55	5.88	292	287
	October	5.59	4.60	282	281
2	January	1.98	2.20	267	271
	April	3.25	2.67	276	275
	July	6.34	3.70	288	281
	October	3.74	2.97	279	276
3	January	1.19	1.32	263	266
	April	2.00	1.40	270	268
	July	3.90	2.20	281	274
	October	2.21	1.85	274	270
4	January	.75	.82	257	259
	April	1.22	.95	264	261
	July	2.51	1.32	276	267
	October	1.37	1.13	268	264
5	January	.44	.47	251	253
	April	.72	.52	258	255
	July	1.56	.80	270	261
	October	.81	.65	262	258

*Keyed to Northern Hemisphere.

TABLE 3 (c)

COMPARISONS OF NORTHERN AND SOUTHERN HEMISPHERE MEAN MOISTURE AND TEMPERATURE DATA SFC - 5 km

(Example of significant differences)

REGION 30

Height (km)	Midseason Month*	Mean Absolute Humidity (g m^{-3}) N. H.	Mean Absolute Humidity (g m^{-3}) (old) S. H.	Mean Temperature ^oK N. H.	Mean Temperature ^oK (old) S. H.
SFC	January	6.20	6.29	289	284
	April	9.11	6.80	296	291
	July	13.17	8.48	305	297
	October	10.25	8.07	301	291
1	January	4.80	4.26	284	280
	April	5.83	4.77	292	286
	July	7.55	6.09	302	293
	October	6.64	5.76	294	287
2	January	2.69	2.23	278	275
	April	3.60	2.84	285	280
	July	4.56	4.03	295	287
	October	3.94	3.36	288	282
3	January	1.47	1.19	273	270
	April	2.00	1.71	279	274
	July	2.51	2.61	289	281
	October	2.23	1.97	281	276
4	January	.87	.67	267	264
	April	1.19	1.01	272	268
	July	1.65	1.64	281	275
	October	1.32	1.20	275	270
5	January	.51	.39	261	258
	April	.69	.57	265	262
	July	1.12	1.04	274	265
	October	.78	.71	268	264

*Keyed to Northern Hemisphere

small moisture amounts in the winter. The data show the seasonal variability to be less for southern hemisphere Region 15.

The remaining region that showed significant differences between hemispheres is Region 26 "major mountain ranges; average elevation 2 to 3 km." Here, the primary difference was in the temperature profiles - the southern hemisphere profiles averaging out significantly higher than the northern hemisphere.

Figures 2-10 illustrate the mean absolute humidity profiles for the nine new regions from the surface to 5 km.

Grid Data vs Station Data Comparison

A second aspect related to refinement of the 4-D atmospheric models was the comparison of the monthly mean and daily variance values computed for southern hemisphere regions (from 5° latitude/longitude grid data) with the values computed from daily station data. The radiosonde data at stations were available for a limited number of southern hemisphere locations. The stations were grouped into their appropriate homogeneous regions and the computed mean and daily variance statistics were averaged for each region. Unfortunately, the number of southern hemisphere stations within each region was far less than the number of 5° latitude/longitude grid points. In many cases only one station (with good data) was available for a region, and there were only three regions where there were more than three stations (considered a bare minimum for comparative purposes). The mean moisture values compared vary favorably for two of these three regions. For Region 29 (border of mountains - subtropics and tropics) there were significant differences. (See Table 4.) Thus, for this region, the station data were averaged into the existing data resulting in only slightly revised profiles (because station data accounted for only approximately 10% of the total data for the region).

Of more importance were the significant differences in the daily variances of moisture (see Table 4). Analysis of the daily standard deviation of dewpoint at constant pressure surfaces from data in Crutcher and Meserve (1971), indi-

Months in Parentheses are Corresponding
Months for Northern Hemisphere

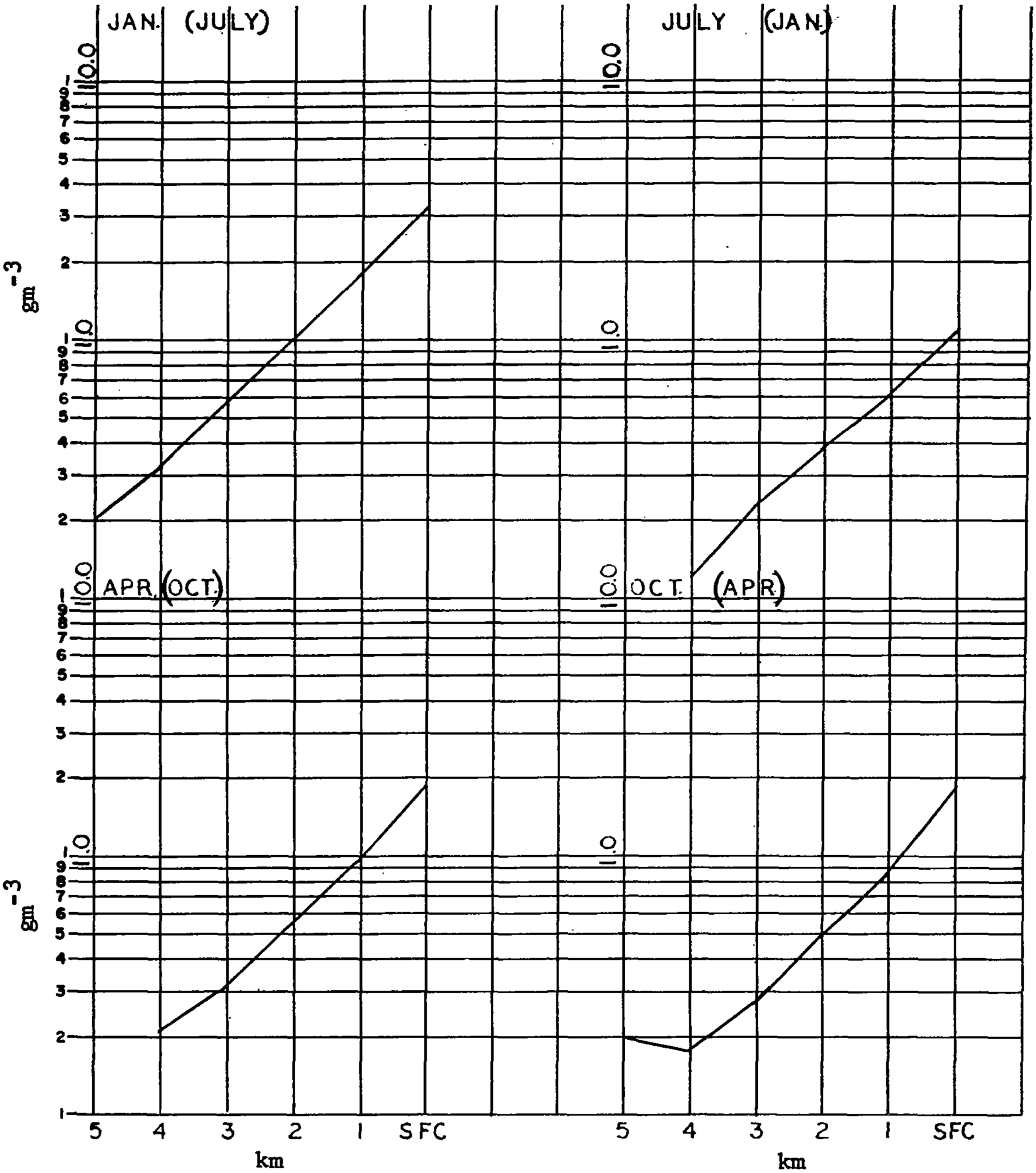


Figure 2. Mean Absolute Humidity (g m^{-3}) vs. Height (km)
Mid-Season Months - Region 37 (1)

Months in Parentheses are Corresponding

Months for Northern Hemisphere

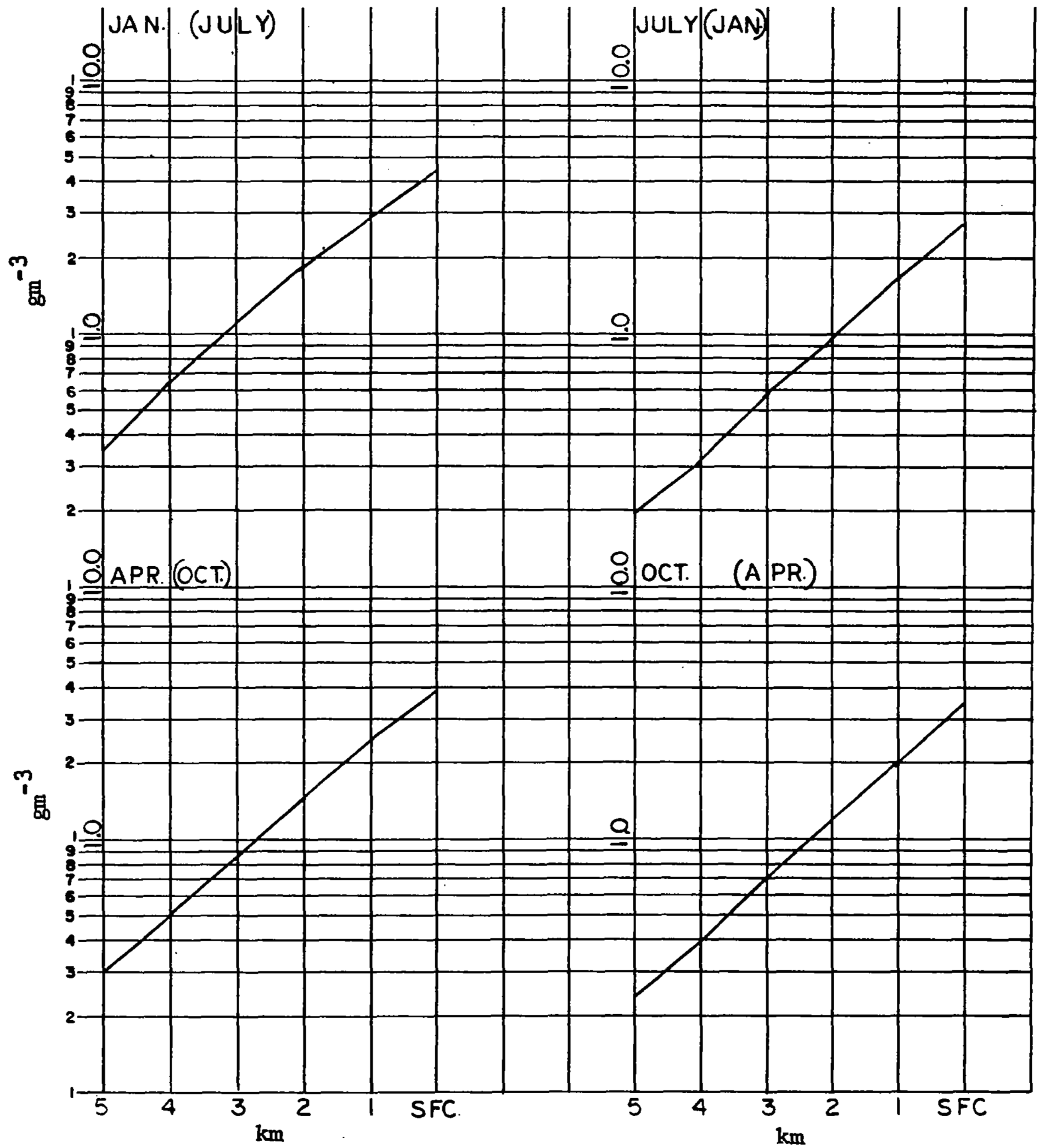


Figure 3. Mean Absolute Humidity (g m^{-3}) vs. Height (km)
Mid-Season Months - Region 38 (2)

Months in Parentheses are Corresponding
Months for Northern Hemisphere

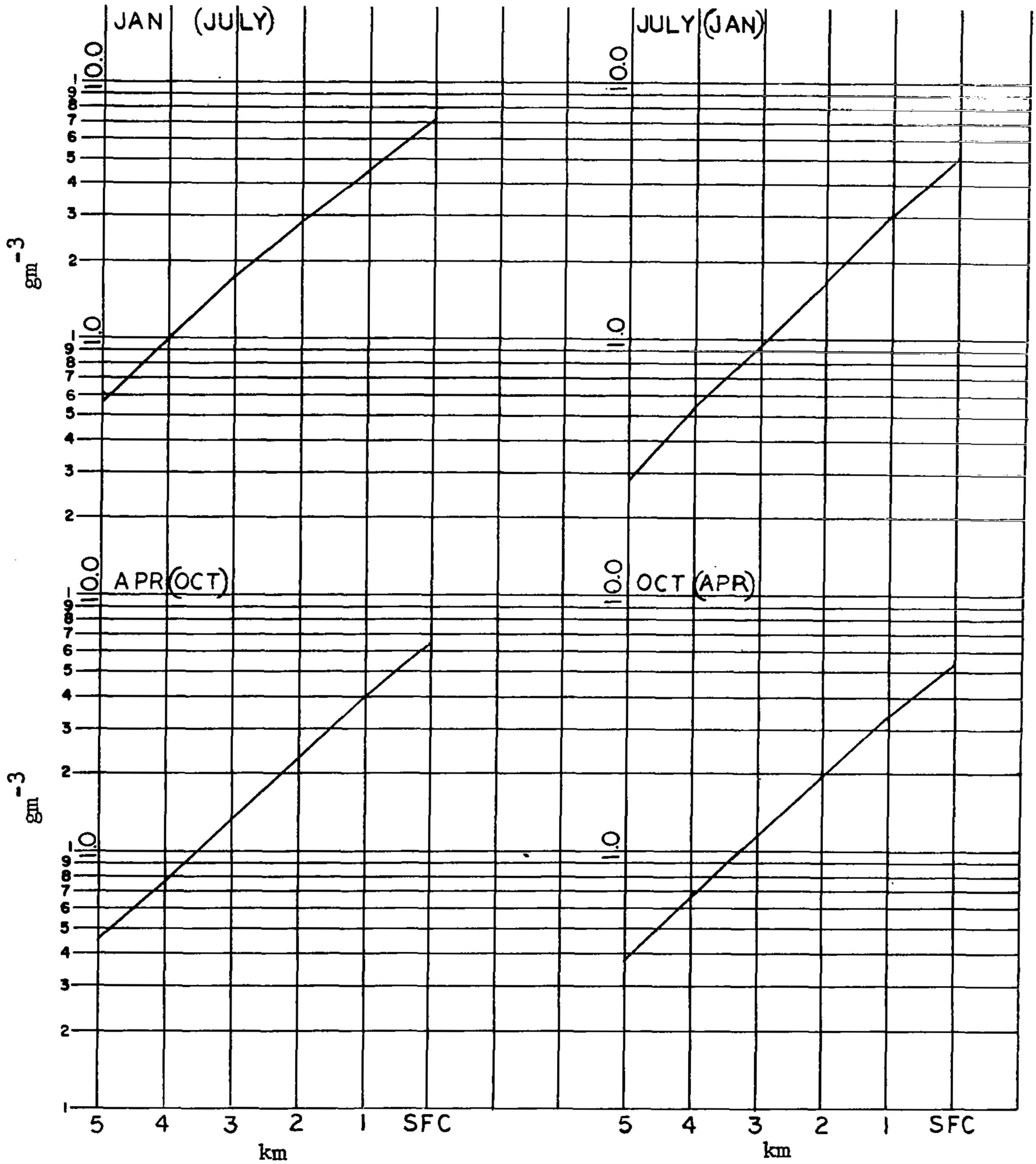


Figure 4. Mean Absolute Humidity (g m^{-3}) vs. Height (km)
Mid-Season Months - Region 39(6)

Months in Parentheses are Corresponding
Months for Northern Hemisphere

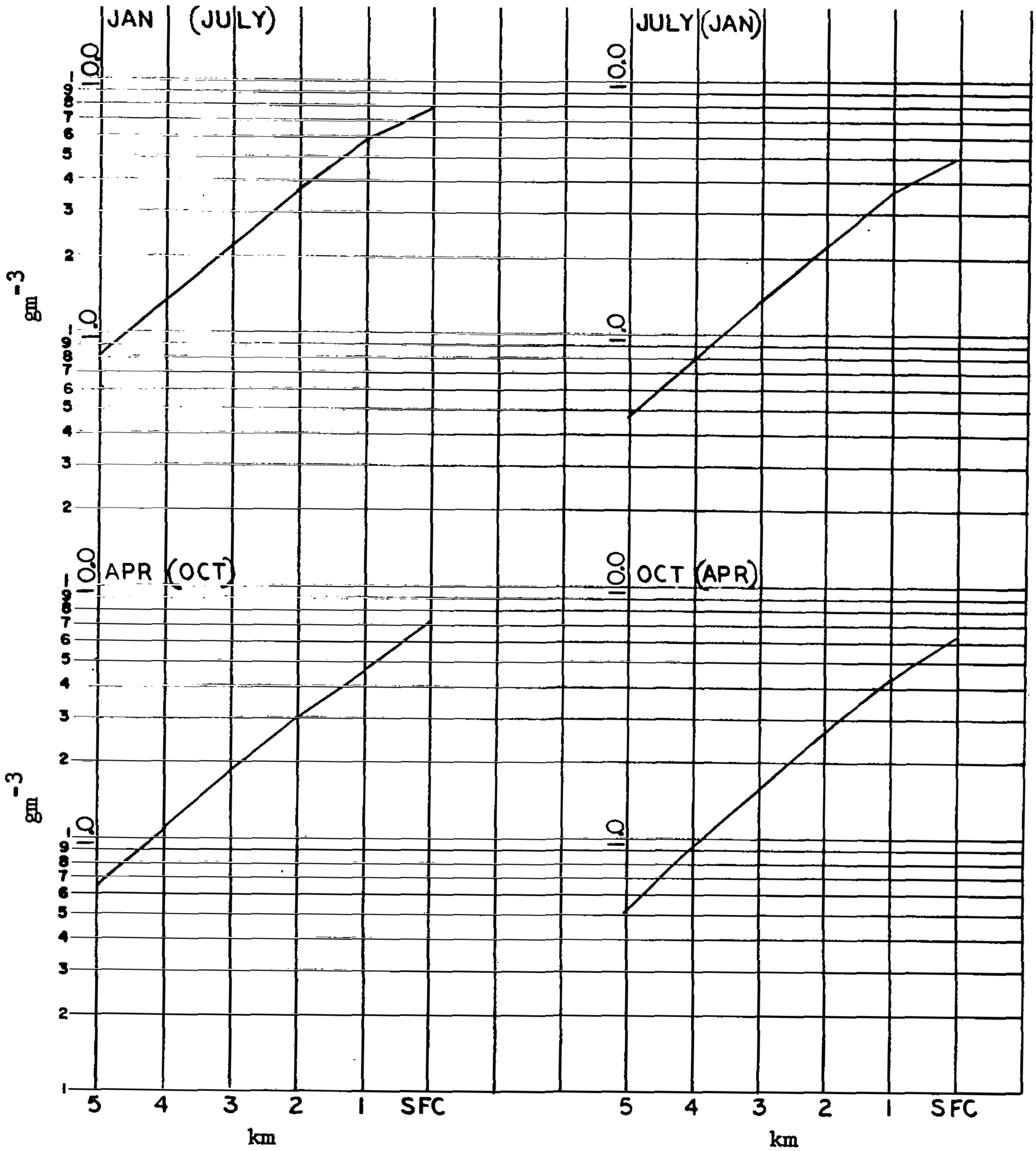


Figure 5. Mean Absolute Humidity (g m^{-3}) vs. Height (km)
Mid-Season Months - Region 40(7)

Months in Parentheses are Corresponding
Months for Northern Hemisphere

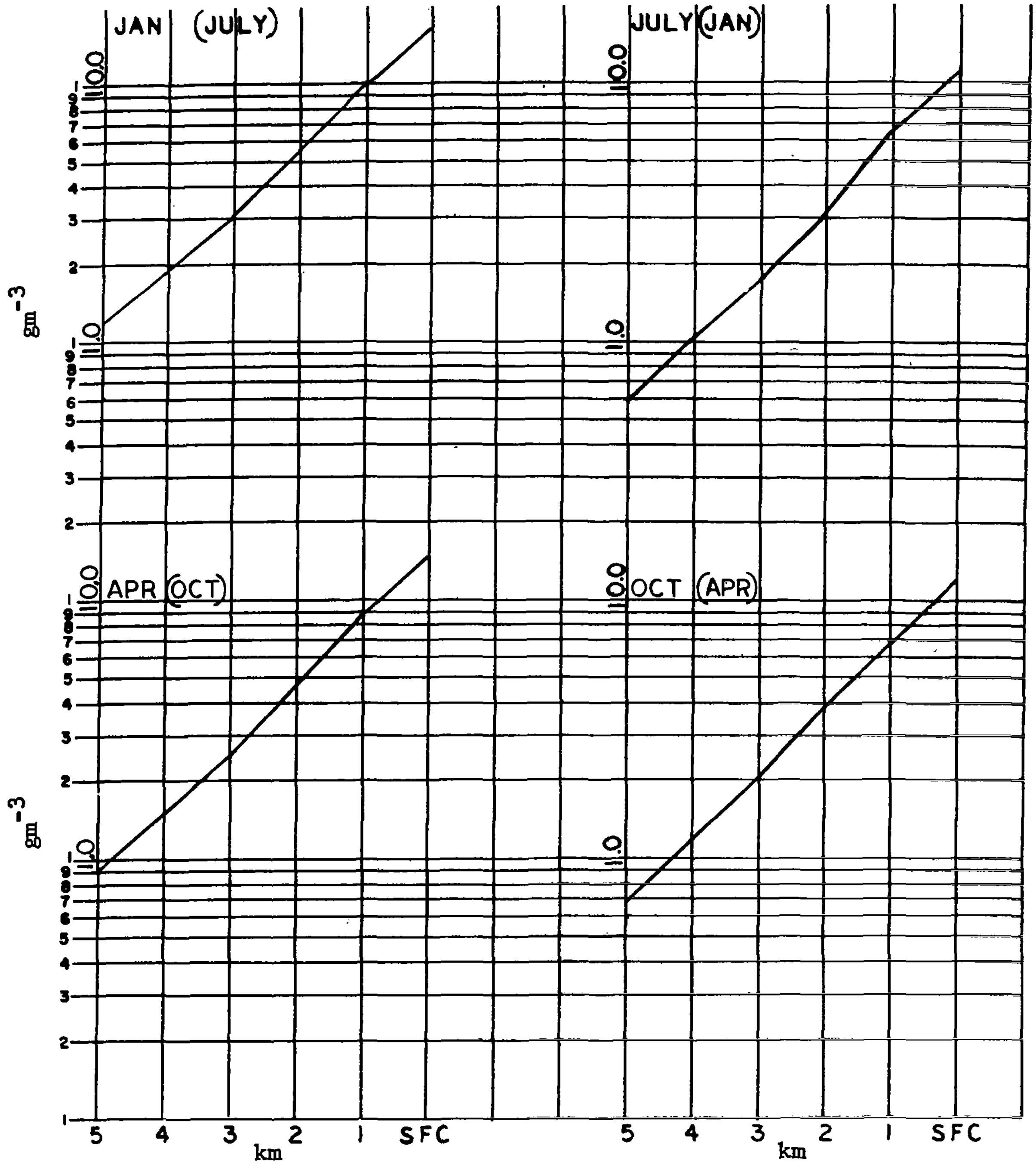


Figure 6. Mean Absolute Humidity (g m^{-3}) vs. Height (km)
Mid-Season Months - Region 41(15)

Months in Parentheses are Corresponding
Months for Northern Hemisphere

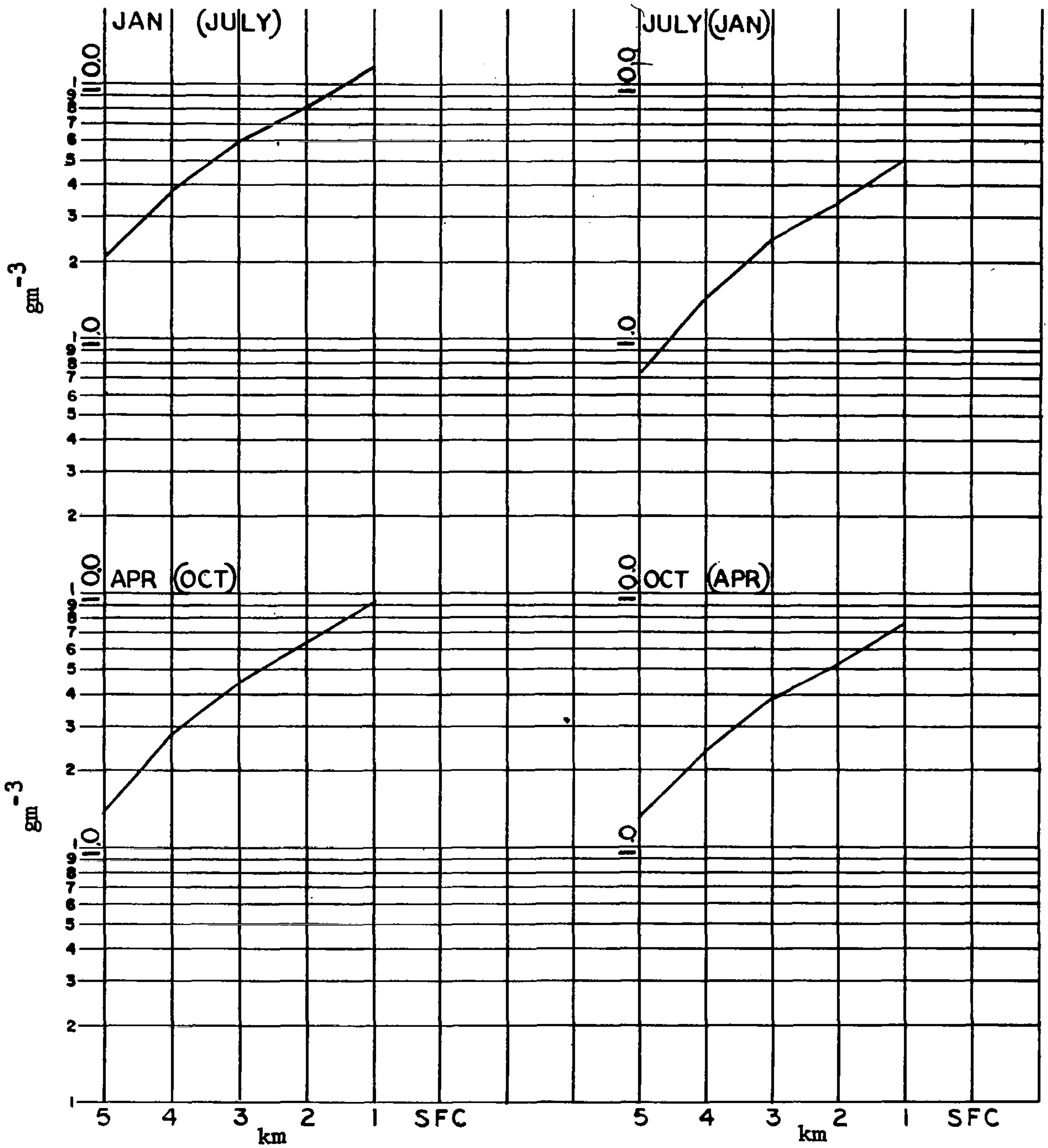


Figure 7. Mean Absolute Humidity (g m^{-3}) vs. Height (km)
Mid-Season Months - Region 42(26)

Months in Parentheses are Corresponding Months for Northern Hemisphere

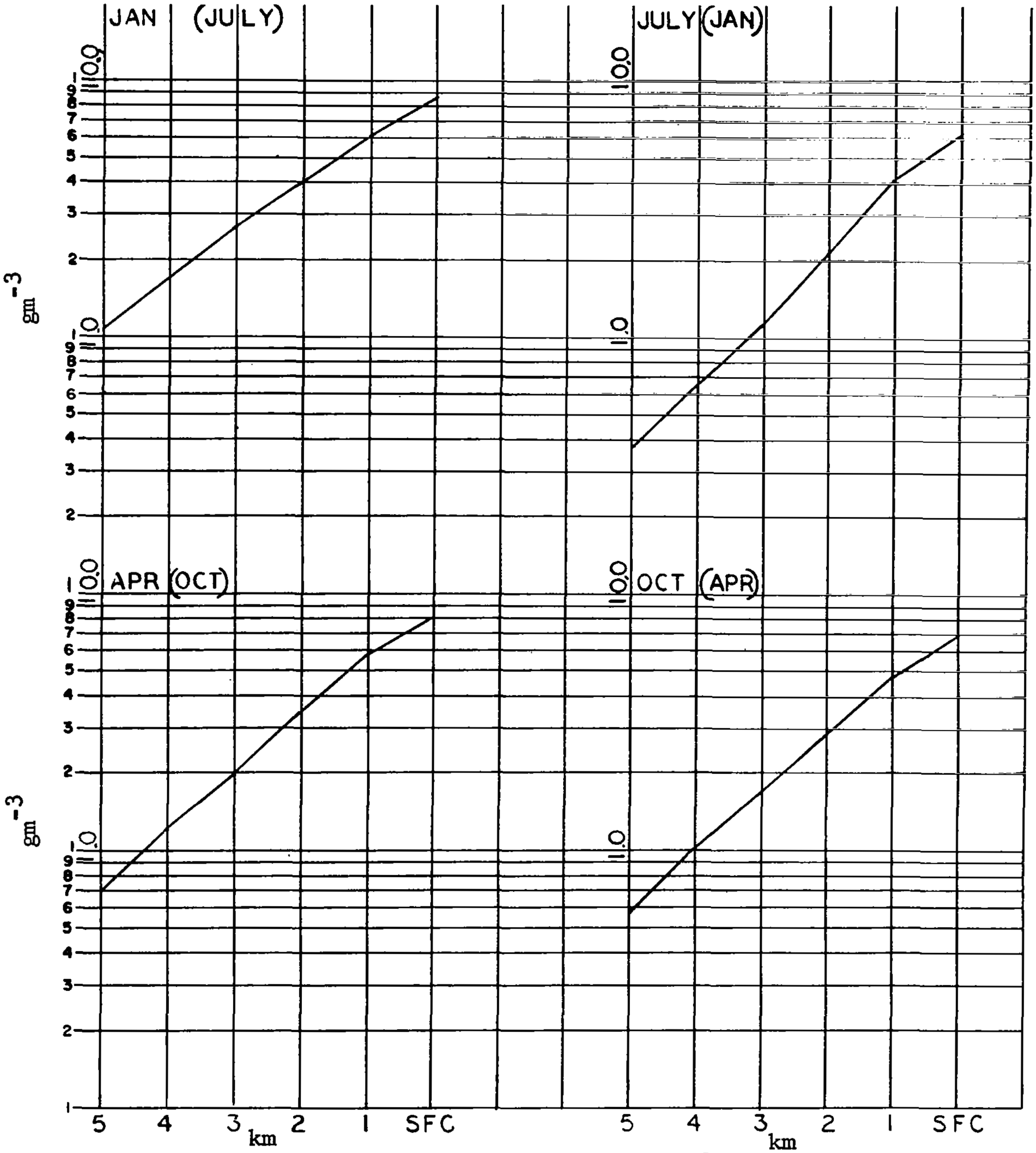


Figure 8. Mean Absolute Humidity (g m^{-3}) vs. Height (km) Mid-Season Months - Region 43(30)

Months in Parentheses are Corresponding
Months for Northern Hemisphere

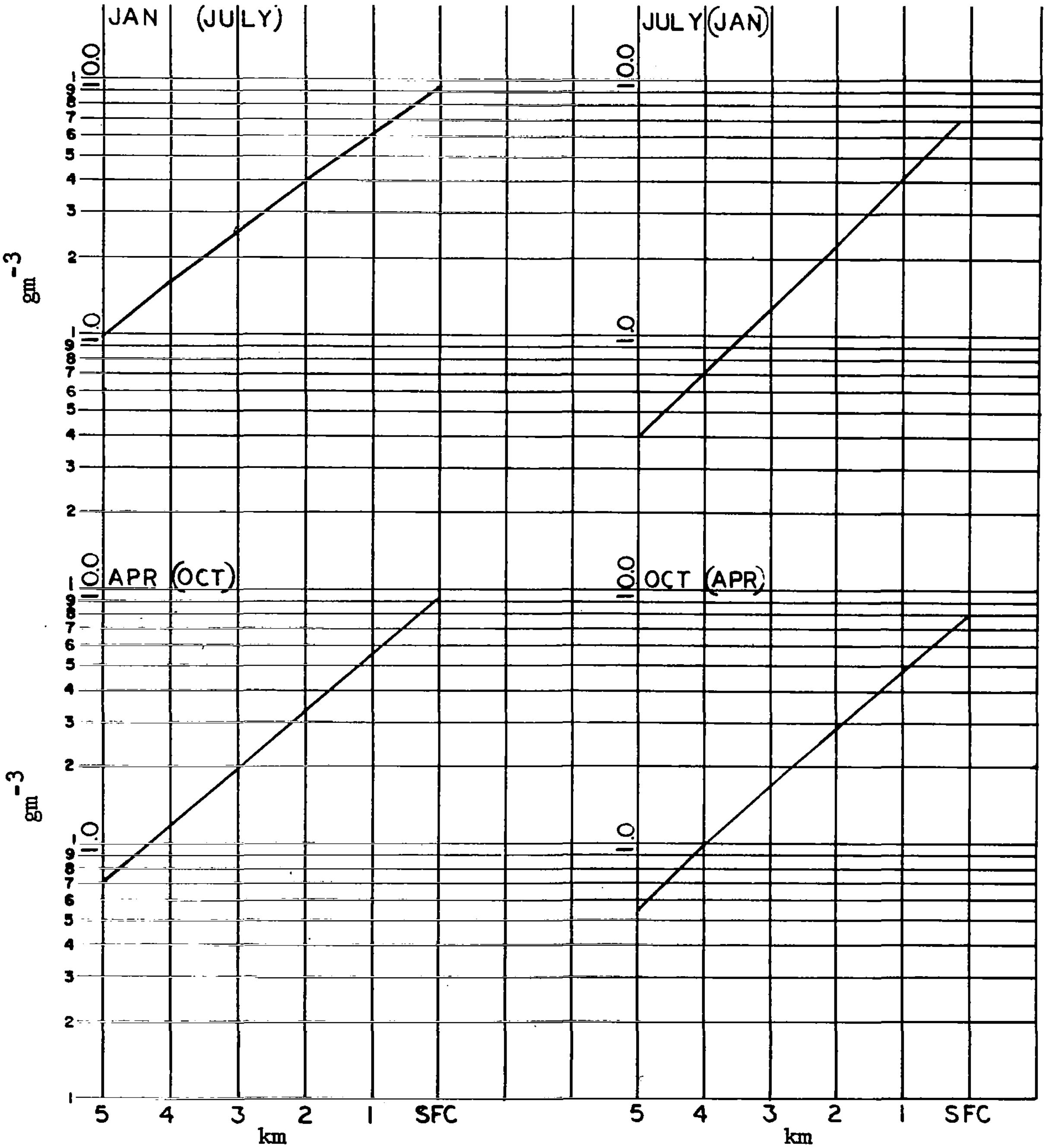


Figure 9. Mean Absolute Humidity (g m^{-3}) vs. Height (km)
Mid-Season Months - Region 44(31)

Months in Parentheses are Corresponding
Months for Northern Hemisphere

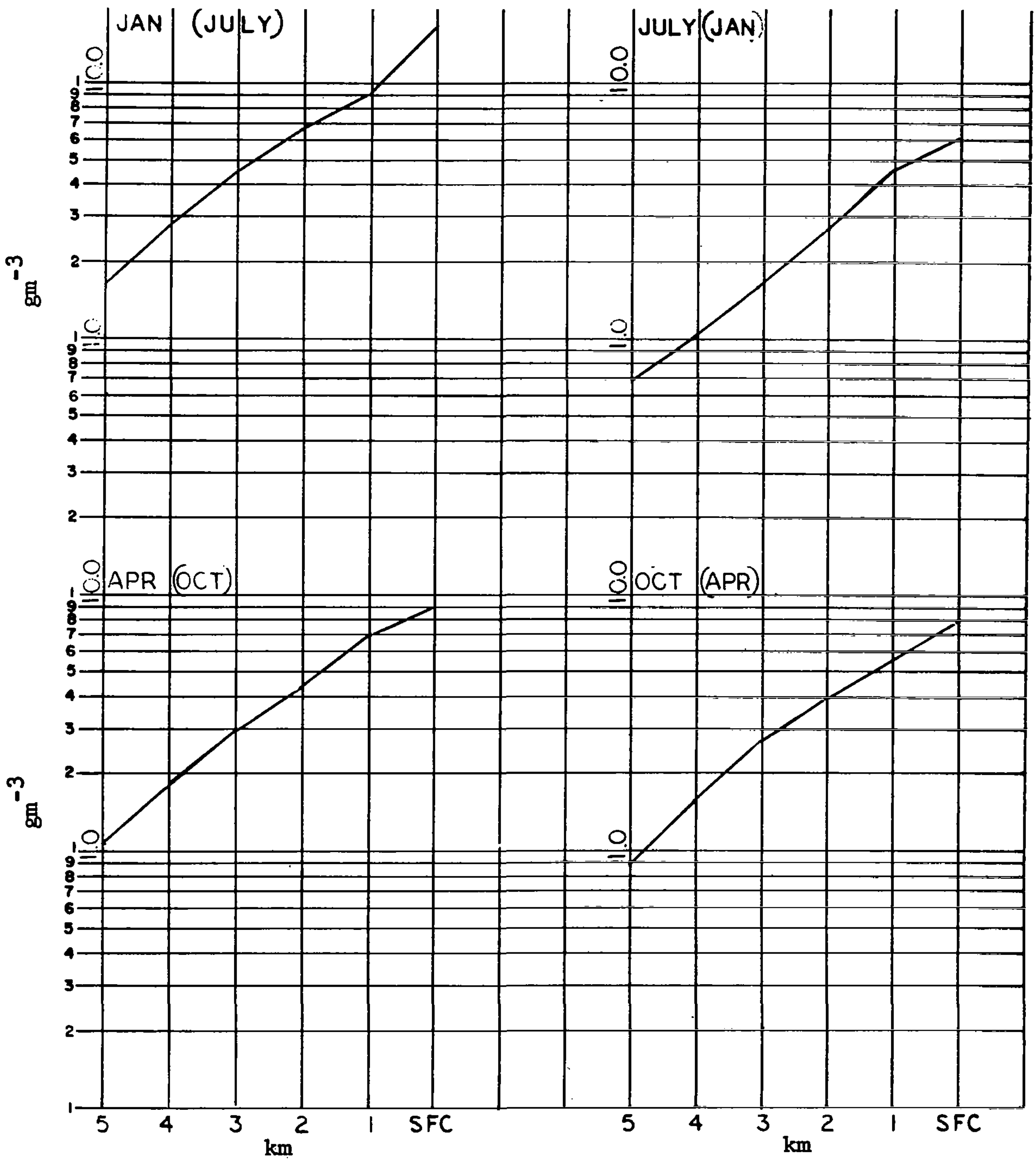


Figure 10. Mean Absolute Humidity (g m^{-3}) vs. Height (km)
Mid-Season Months - Region 45(33)

cates that the variability of the standard deviation across a homogeneous moisture region is generally very small. The significant differences in variances between station and regional means computed from grid point values prompted an examination of individual grid point values for daily moisture variances for the southern hemisphere. The purpose here was to determine to what extent unrealistic values were computed by the procedure used in the previous study; i. e.,

$$\text{S. H. (daily)} = \text{S. H. (monthly)} \times \text{N. H.} \left(\frac{\text{daily}}{\text{monthly}}\right)$$

where

S. H. refers to southern hemisphere variances at latitude/longitude points

and

N. H. refers to northern hemisphere variance ratios at latitude/longitude points.

(Reversal of seasons was accounted for in the above computations.)

The analysis of individual point values of moisture variances showed that approximately 25% of the points (mostly at tropical latitudes) had unrealistically high values. Combined values for homogeneous regions had not reflected this deficiency. Reliable values at individual points were required for use in the technique that provides 4-D atmospheric profiles at any point on the globe (not as a function of homogeneous region).

The cause for the unrealistic high values is that the simple assumption inherent in the computations is not valid everywhere. The computation assumes that the southern hemisphere is a mirror image of the northern hemisphere and that the daily/monthly variance for, say, the month of January at 20° N, 60° W (in the tropical Atlantic Ocean) applies to the month of July at 20° S and 60° W (in the middle of South America). Thus, one can understand why the assumption may not always be justified.

To overcome the problem of the inaccurate daily variances for 25% of the southern hemisphere points, a new procedure was developed to generate daily variance values. The procedure is based upon information from corresponding homogeneous regions rather than for particular latitudes and longitudes as it was previously. The rationale for this method is that, by definition, a homogeneous region in the southern hemisphere is nearly identical in nature to the same (type) region in the northern hemisphere, and that the relationship given by the ratio of the standard deviation of the mean absolute humidity to the mean absolute humidity is conservative for a homogeneous region. Thus, the standard deviation of mean absolute humidity for southern hemisphere points is obtained by determining in which region the point is located and the computation given by:

$$\sigma W_{(S.H.P)} = \overline{W}_{(S.H.P)} \times \left(\frac{\sigma W}{\overline{W}} \right)_{(N.H.P)}$$

where

$\overline{W}$ is the mean absolute humidity

σW is the standard deviation of the absolute humidity

S. H. P is the southern hemisphere point

and

N. H. P refers to the value of the ratio in the northern hemisphere region that corresponds to the region in which the southern hemisphere point is located.

This procedure was incorporated into the processing program for southern hemisphere points, and the regional values were recalculated. Southern hemisphere variance statistics for absolute humidity at km levels were thereby improved both for homogeneous moisture regions and individual data points. Table 5 shows moisture variances at the surface for five points after our new procedure was used. Previous variance values at these points exceeded 24 in all cases. The results are what would be expected in tropical regions and clearly demonstrate the improvement in the data related to the new method (i. e., the unrealistically high values are eliminated).

TABLE 4(a)

MEAN ABSOLUTE HUMIDITY AND VARIANCE STATISTICS;
SURFACE TO 5 km FOR REGIONS 6, 8, AND 29 IN SOUTHERN HEMISPHERE -
GRIDPOINT vs. STATION COMPARISON - JANUARY

Level	Region	Gridpoint/Station Month	Gridpoint/Station Cases	Absolute Humidity g m^{-3}			
				Mean		Variance	
				Grid Pt	Sta.	Grid Pt	Sta.
SFC				7.27	7.48	12.46	1.98
1				4.48	5.13	5.84	2.34
2				2.78	3.46	2.60	2.07
3	6	1	153/4	1.65	2.30	1.03	1.40
4				1.00	1.48	.46	.76
5				.59	.98	.21	.36
SFC				10.90	9.94	12.72	3.31
1				6.47	6.69	6.22	3.35
2				3.78	4.08	3.14	3.25
3	8	1	107/5	2.13	2.41	1.40	1.66
4				1.30	1.61	.65	.82
5				.77	1.06	.31	.37
SFC				18.13	12.38	10.39	.99
1				13.49	9.02	3.80	1.86
2				9.03	5.48	7.56	2.56
3	29	1	12/4	5.04	3.61	5.07	1.67
4				3.42	2.60	3.07	.98
5				2.09	1.77	.80	.66

TABLE 4(b)

MEAN ABSOLUTE HUMIDITY AND VARIANCE STATISTICS;
SURFACE TO 5 km FOR REGIONS 6, 8, AND 29 IN SOUTHERN HEMISPHERE -
GRIDPOINT vs. STATION COMPARISON - APRIL

Level	Region	Gridpoint/Station Month	Gridpoint/Station Cases	Absolute Humidity g m^{-3}			
				Mean		Variance	
				Grid Pt	Sta.	Grid Pt	Sta.
SFC				6.48	6.73	10.85	1.86
1				4.05	4.37	5.22	1.71
2				2.32	2.69	1.86	1.45
3	6	4	153/4	1.32	1.72	.68	.98
4				.79	1.09	.30	.42
5				.45	.72	.13	.21
SFC				9.61	8.98	11.25	3.09
1				5.67	6.06	5.24	2.73
2				3.70	3.65	2.37	2.76
3	8	4	107/5	1.74	2.05	.96	1.52
4				1.04	1.39	.41	.77
5				.62	.93	.20	.37
SFC				16.88	11.83	8.72	.91
1				11.96	8.23	2.97	2.47
2				7.96	5.15	6.51	1.93
3	29	4	12/4	4.32	3.53	4.69	1.11
4				2.86	2.57	3.13	.56
5				1.68	1.87	.71	.39

TABLE 4(c)

MEAN ABSOLUTE HUMIDITY AND VARIANCE STATISTICS; SURFACE TO 5 km FOR REGIONS 6, 8, AND 29 IN SOUTHERN HEMISPHERE - GRIDPOINT vs. STATION COMPARISON - JULY

Level	Region	Gridpoint/Station Month	Gridpoint/Station Cases	Absolute Humidity g m^{-3}			
				Mean		Variance	
				Grid Pt	Sta.	Grid Pt	Sta.
SFC				5.17	5.57	8.00	1.20
1				3.11	3.66	3.34	1.48
2				1.71	7.10	1.17	1.08
3	6	7	153/4	.93	1.30	.37	.56
4				.54	.82	.16	.24
5				.30	.52	.06	.10
SFC				7.47	7.27	8.56	2.06
1				4.41	4.71	4.10	1.82
2				2.31	2.73	1.36	1.64
3	8	7	107/5	1.20	1.57	.51	.90
4				.69	1.04	.21	.41
5				.39	.67	.09	.24
SFC				13.63	9.86	5.65	.71
1				8.09	6.67	1.47	2.25
2	29	7	12/4	5.43	3.47	5.01	1.03
3				2.53	2.46	2.06	.49
4				1.64	1.84	1.35	.38
5				.97	1.25	.32	.36

TABLE 4(d)

MEAN ABSOLUTE HUMIDITY AND VARIANCE STATISTICS;

SURFACE TO 5 km FOR REGIONS 6, 8, AND 29 IN SOUTHERN HEMISPHERE - GRIDPOINT vs. STATION COMPARISON - OCTOBER

Level	Region	Gridpoint/Station Month	Gridpoint/Station Cases	Absolute Humidity g m^{-3}			
				Mean		Variance	
				Grid Pt	Sta.	Grid Pt	Sta.
SFC				5.54	5.94	4.88	1.34
1				3.38	3.88	2.08	1.22
2				1.97	2.44	1.01	1.02
3	6	10	153/4	1.11	1.47	.53	.66
4				.65	.93	.19	.29
5				.37	.60	.07	.13
SFC				8.09	7.92	10.95	2.07
1				4.77	5.22	4.50	1.88
2				2.69	3.10	1.61	1.80
3	8	10	107/5	1.46	1.80	.61	1.05
4				.86	1.22	.22	.52
5				.50	.80	.08	.23
SFC				15.76	10.41	24.85	.70
1				10.44	7.61	9.66	2.16
2				6.99	4.04	5.43	1.53
3	29	10	12/4	3.90	2.92	1.14	.90
4				2.50	2.20	.51	.58
5				1.45	1.50	.19	.46

TABLE 5

MOSITURE AND MOISTURE VARIANCES (g m^{-3}) FOR FIVE SOUTHERN HEMISPHERE POINTS (JANUARY) FOR NEW VARIANCE PROCEDURES USED.

Point		g m^{-3}	g m^{-3}
Latitude	Longitude	Water	Variance
0	0	21.80	2.55
5	0	19.10	1.23
10	0	16.80	1.33
10	20	17.20	.86
15	25	17.80	1.05

3. TECHNIQUE FOR OBTAINING "TRUE" MEAN MONTHLY ATMOSPHERIC PROFILES AND DAILY VARIANCES ANYWHERE ON THE GLOBE

The operational 4-D atmospheric model computer program currently accepts as input the latitude, longitude and month of year. It then determines in which homogeneous region the given latitude/longitude point is located and generates mean monthly profiles and daily variances which represent averages of all points within the region for the desired month. Despite the fact that the homogeneous moisture regions were defined to possess the characteristic of minimum variability across the regions, there may be significant gradients of moisture over relatively short distances in some regions at certain times of the year. It is desirable for some operational procedures to have more accurate information as represented by "true" profiles at any point on the globe for any month. A computer program was developed to provide this capability. All grid point data (global) to be used with this program are packed onto three magnetic tapes.

Because the homogeneous region data set is considerably smaller than the data set for individual points, the original computer program requires less storage and less time to run than the one developed for individual points. Thus, for planning purposes, research efforts and preliminary mission simulations, one might continue to want to use the program that generates atmospheric profiles as a function of homogeneous region.

Figure 11 represents a flow (block) diagram of the computer program developed for true mean monthly profiles and daily variances for individual points. The interpolations referred to in the flow diagram are the following:

1. <u>For Northern Hemisphere Numerical Weather Prediction (NMC) Grid</u>

Interpolation to a latitude-longitude point is made directly from the four-point interpolation program given in Jenne (1970).

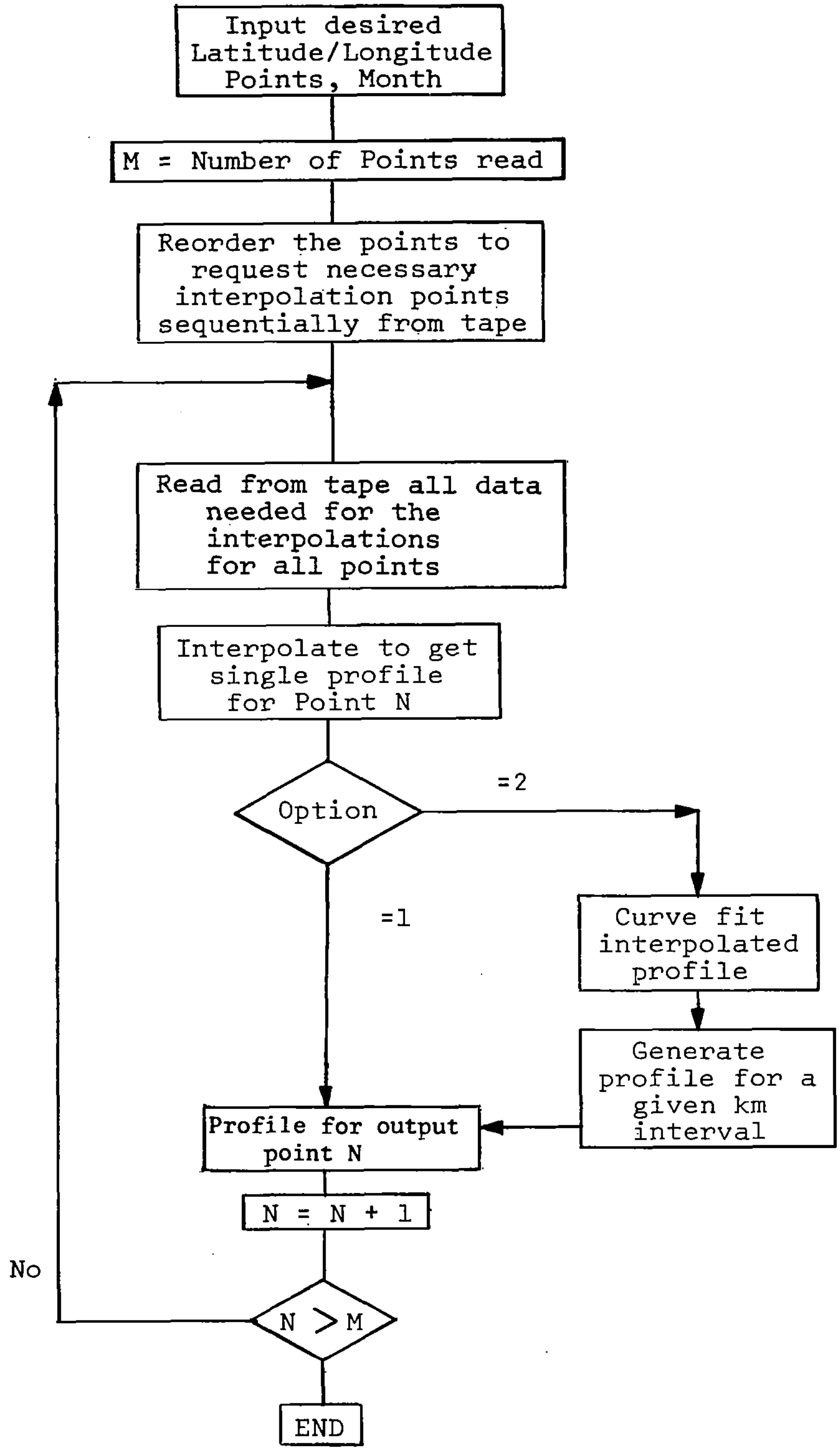


Figure 11. Flow Diagram of Computer Program to Obtain Atmospheric Profile(s) at any point(s) on the Globe.

2. For Northern Hemisphere 5° Latitude-Longitude Equatorial Grid

Curvilinear interpolation equation used:

$$S(x, y) = a + bx + cy + dxy \quad (1)$$

$$a = G(0, 0) \quad (2)$$

$$b = G(1, 0) - G(0, 0) \quad (3)$$

$$c = G(0, 1) - G(0, 0) \quad (4)$$

$$d = G(1, 1) - G(0, 1) - G(1, 0) + G(0, 0) \quad (5)$$

$$x = [(\cos\phi\Big|_{G(1,0)} + \cos\phi\Big|_{S(x,y)})/2][\lambda\Big|_{G(0,0)} - \lambda\Big|_{S(x,y)}]/5 \quad (6)$$

$$y = [\phi\Big|_{S(x,y)} - \phi\Big|_{G(0,0)}]/5 \quad (7)$$

where ϕ is the latitude

and λ is the longitude

x and y are in degrees latitude divided by 5.

To keep x positive: all longitudes are in west longitude; i.e., longitude increased in clockwise direction from 0° through 180° making 170° east longitude = 190° and 160° east longitude = 200°, etc. See Figure 12 for reference system.

3. For Southern Hemisphere 5° Latitude-Longitude Grid

Curvilinear interpolation equation (1) is used. Constants the same as in Eq. (2) through Eq. (5), but the reference system is different to keep y positive (see Figure 13). Similar to the northern hemisphere, all longitudes are in °W from 0° meridian to keep x positive.

For the special cases of interpolation of a point between the NMC grid and the 5° latitude-longitude grid in the deep tropical latitudes of the northern hemisphere, the quadrilateral formed by the four points will, in general, not be a square. For these cases, the axes formed by the four points are rotated to the x, y latitude-longitude coordinate system, the angles between the latitude-

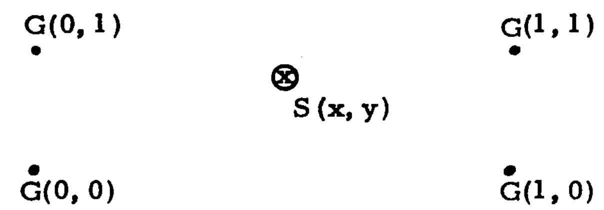


Figure 12. Reference System for 5° Latitude-Longitude Interpolation (Northern Hemisphere)

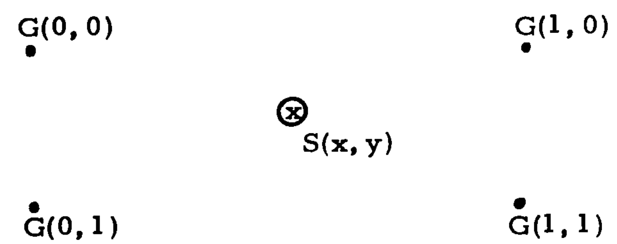


Figure 13. Reference System for 5° Latitude-Longitude Interpolation (Southern Hemisphere)

longitude axes and the axes formed by the four points computed and the coefficients in the system of Eqs. (2) through (5) solved in terms of the appropriate angles and distances.

Examples of interpolated profiles are given in Table 6 and Figures 14-16 for a few selected points.

To summarize, this program provides the capability of determining mean monthly profiles of moisture, temperature, pressure and density for any point(s) on the globe and month(s) of the year. These profiles are not a function of homogeneous moisture region and can therefore supply more accurate data than previously possible as input to atmospheric attenuation models that predict electromagnetic sensor degradation effects. For planning purposes and preliminary mission simulations (as opposed to operational purposes) one might continue to want to use the atmospheric profiles that are a function of homogeneous regions.

TABLE 6a MEANS AND VARIANCES FOR POINT 7

DATA SOURCE 3

LATITUDE 30.0S LONGITUDE 0.0W JANUARY

LEVEL	PRESSURE mb	VARIANCE mb	TEMP °A	VARIANCE °A	WATER g m^{-3}	VARIANCE g m^{-3}	DENSITY g m^{-3}	VARIANCE g m^{-3}
SFC	1019.50	3.37	293.60	16.47	12.90	1.02	1209.80	279.65
1 KM	906.60	2.77	288.00	16.47	7.50	1.02	1096.60	238.78
2 KM	805.10	2.20	284.60	14.31	4.20	1.02	985.40	171.52
3 KM	713.40	1.73	280.10	10.12	2.30	.44	887.20	101.54
4 KM	629.90	2.58	275.00	10.31	1.40	.21	798.10	86.84
5 KM	555.70	3.57	269.70	11.20	.80	.08	717.80	79.31
6 KM	490.40	4.43	264.10	11.80	.47	.03	647.00	70.81
7 KM	430.20	5.08	256.70	10.61	.28	.01	583.90	54.92
8 KM	375.90	5.52	249.30	9.49	.16	.01	525.40	42.16
9 KM	327.20	5.73	241.80	8.43	.10	0.00	471.30	32.04
10 KM	283.10	5.62	234.80	7.11	.06	0.00	420.00	22.74
11 KM	244.30	5.23	228.40	5.46	.03	0.00	372.60	14.52
12 KM	209.90	4.78	222.00	4.03	.02	0.00	329.50	8.87
13 KM	179.50	3.42	217.10	3.72	.01	0.00	288.00	6.54
14 KM	153.10	2.18	213.00	3.85	.01	0.00	250.50	5.32
15 KM	130.20	1.35	208.80	3.98	0.00	0.00	217.30	4.31
16 KM	110.40	.82	204.70	4.11	0.00	0.00	188.00	3.47
17 KM	93.10	.50	203.60	3.93	0.00	0.00	159.30	2.40
18 KM	78.80	.32	206.80	3.34	0.00	0.00	132.80	1.38
19 KM	66.90	.20	209.90	2.80	0.00	0.00	111.10	.78
20 KM	56.90	.13	213.00	2.30	0.00	0.00	93.10	.44
21 KM	48.70	.11	215.90	1.91	0.00	0.00	78.50	.25
22 KM	41.60	.26	217.80	1.78	0.00	0.00	66.50	.17
23 KM	35.60	.38	219.80	1.66	0.00	0.00	56.40	.11
24 KM	30.50	.47	221.70	1.54	0.00	0.00	47.90	.07
25 KM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TABLE 6b MEANS AND VARIANCES FOR POINT 8

DATA SOURCE 3

LATITUDE -35.0S LONGITUDE 0.0W JANUARY

LEVEL	PRESSURE mb	VARIANCE mb	TEMP °A	VARIANCE °A	WATER $g\ m^{-3}$	VARIANCE $g\ m^{-3}$	DENSITY $g\ m^{-3}$	VARIANCE $g\ m^{-3}$
SFC	1019.30	6.52	290.80	7.52	12.20	1.17	1221.10	132.60
1 KM	905.40	5.32	285.80	7.52	6.90	1.17	1103.90	112.19
2 KM	803.10	4.39	282.10	9.75	4.00	1.17	991.70	120.50
3 KM	710.90	3.70	277.80	15.41	2.10	.51	891.60	158.73
4 KM	627.10	4.95	272.60	13.31	1.30	.23	801.50	115.04
5 KM	552.60	6.25	267.20	10.44	.80	.10	720.40	75.86
6 KM	486.60	7.19	261.50	8.80	.49	.04	648.40	54.12
7 KM	426.30	7.53	254.20	10.81	.30	.02	584.30	57.13
8 KM	372.00	7.62	246.80	13.03	.19	.01	525.00	58.96
9 KM	323.30	7.49	239.50	15.45	.12	0.00	470.30	59.59
10 KM	279.80	7.30	232.70	15.22	.07	0.00	418.90	49.32
11 KM	241.20	7.07	226.50	12.17	.04	0.00	371.00	32.64
12 KM	207.00	6.66	220.20	9.45	.03	0.00	327.50	20.91
13 KM	176.70	4.56	216.80	8.28	.02	0.00	283.90	14.20
14 KM	150.80	2.85	214.20	7.50	.01	0.00	245.30	9.83
15 KM	128.50	1.75	211.50	6.75	.01	0.00	211.60	6.76
16 KM	109.20	1.05	208.90	6.04	0.00	0.00	182.10	4.59
17 KM	92.50	.63	208.50	5.26	0.00	0.00	154.50	2.89
18 KM	78.60	.40	210.70	4.40	0.00	0.00	129.90	1.67
19 KM	66.90	.25	212.90	3.63	0.00	0.00	109.40	.96
20 KM	57.00	.15	215.10	2.93	0.00	0.00	92.30	.54
21 KM	48.70	.12	217.20	2.36	0.00	0.00	78.10	.31
22 KM	41.60	.24	218.90	2.15	0.00	0.00	66.30	.20
23 KM	35.70	.34	220.60	1.94	0.00	0.00	56.30	.13
24 KM	30.60	.40	222.30	1.74	0.00	0.00	47.90	.08
25 KM	26.64	0.00	224.05	0.00	0.00	0.00	41.43	0.00

TABLE 6c MEANS AND VARIANCES FOR POINT 25

DATA SOURCE 3

LATITUDE 35.0S LONGITUDE 5.0 W JANUARY

LEVEL	PRESSURE mb	VARIANCE mb	TEMP °A	VARIANCE °A	WATER g m^{-3}	VARIANCE g m^{-3}	DENSITY g m^{-3}	VARIANCE g m^{-3}
SFC	1019.40	14.53	291.30	8.25	12.20	1.17	1219.20	144.52
1 KM	905.70	11.91	285.90	8.25	7.10	1.17	1103.70	122.95
2 KM	803.40	10.02	282.20	10.80	4.00	1.17	991.90	133.41
3 KM	711.20	8.83	277.60	17.34	2.20	.56	892.40	179.20
4 KM	627.20	9.49	272.40	15.61	1.40	.27	802.20	135.40
5 KM	552.60	10.07	267.00	12.92	.80	.10	721.00	94.25
6 KM	486.50	10.20	261.30	11.55	.48	.04	648.70	71.19
7 KM	426.10	9.60	254.00	14.47	.29	.02	584.50	76.62
8 KM	371.80	8.89	246.70	17.72	.18	.01	525.10	80.27
9 KM	323.20	8.12	239.40	21.29	.11	0.00	470.30	82.17
10 KM	279.70	7.19	232.60	19.96	.06	0.00	418.90	64.75
11 KM	241.00	6.18	226.30	13.88	.04	0.00	371.00	37.30
12 KM	206.90	5.26	220.10	8.90	.02	0.00	327.50	19.70
13 KM	176.60	3.66	216.80	7.55	.01	0.00	283.80	12.94
14 KM	150.70	2.40	214.20	7.00	.01	0.00	245.10	9.16
15 KM	128.40	1.56	211.60	6.46	.01	0.00	211.40	6.45
16 KM	109.10	1.00	209.00	5.95	0.00	0.00	181.90	4.50
17 KM	92.30	.63	208.70	5.25	0.00	0.00	154.10	2.86
18 KM	78.50	.39	210.90	4.40	0.00	0.00	129.60	1.66
19 KM	66.80	.25	213.00	3.62	0.00	0.00	109.20	.95
20 KM	56.90	.15	215.20	2.92	0.00	0.00	92.20	.54
21 KM	48.70	.12	217.20	2.36	0.00	0.00	78.00	.30
22 KM	41.60	.24	218.90	2.14	0.00	0.00	66.20	.20
23 KM	35.60	.34	220.60	1.94	0.00	0.00	56.20	.13
24 KM	30.50	.40	222.30	1.74	0.00	0.00	47.80	.08
25 KM	26.64	0.00	224.05	0.00	0.00	0.00	41.43	0.00

TABLE 6d MEANS AND VARIANCES FOR POINT 24

DATA SOURCE 3

LATITUDE 30.0S LONGITUDE 5.0 W JANUARY

LEVEL	PRESSURE mb	VARIANCE mb	TEMP ^{o}A	VARIANCE ^{o}A	WATER g m^{-3}	VARIANCE g m^{-3}	DENSITY g m^{-3}	VARIANCE g m^{-3}
SFC	1020.00	6.22	294.20	3.84	13.10	1.07	1207.90	64.73
1 KM	907.20	5.13	288.10	3.84	7.70	1.07	1096.90	55.66
2 KM	805.70	3.96	284.70	6.69	4.30	1.07	985.80	80.18
3 KM	713.90	2.91	280.00	15.73	2.30	.44	888.30	158.33
4 KM	630.10	3.30	274.80	15.42	1.40	.21	798.90	130.33
5 KM	555.90	3.78	269.50	13.27	.80	.08	718.50	94.33
6 KM	490.50	4.20	263.90	11.62	.47	.03	647.50	69.97
7 KM	430.20	4.93	256.40	11.98	.28	.01	584.50	62.24
8 KM	375.80	5.43	248.90	12.34	.16	.01	526.00	55.09
9 KM	327.00	5.71	241.50	12.70	.10	0.00	471.90	48.49
10 KM	283.00	5.47	234.40	11.22	.06	0.00	420.60	36.12
11 KM	244.20	4.79	228.00	7.51	.03	0.00	373.10	20.12
12 KM	209.80	4.15	221.50	4.55	.02	0.00	329.90	10.09
13 KM	179.20	2.96	216.80	3.87	.01	0.00	287.90	6.83
14 KM	152.80	1.94	212.80	3.96	.01	0.00	250.20	5.47
15 KM	130.00	1.25	208.80	4.05	0.00	0.00	216.90	4.37
16 KM	110.20	.79	204.70	4.14	0.00	0.00	187.50	3.47
17 KM	92.90	.49	203.90	3.92	0.00	0.00	158.70	2.37
18 KM	78.70	.31	206.90	3.33	0.00	0.00	132.40	1.36
19 KM	66.80	.20	210.00	2.79	0.00	0.00	110.80	.78
20 KM	56.80	.13	213.10	2.30	0.00	0.00	92.90	.44
21 KM	48.60	.11	216.00	1.91	0.00	0.00	78.40	.25
22 KM	41.50	.26	217.90	1.78	0.00	0.00	66.40	.17
23 KM	35.50	.38	219.70	1.66	0.00	0.00	56.30	.11
24 KM	30.40	.47	221.60	1.54	0.00	0.00	47.80	.07
25 KM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TABLE 6e MEANS AND VARIANCES FOR LATITUDE 34.8S LONGITUDE 4.8 W JANUARY

LEVEL	PRESSURE mb	VARIANCE mb	TEMP °A	VARIANCE °A	WATER g m^{-3}	VARIANCE g m^{-3}	DENSITY g m^{-3}	VARIANCE g m^{-3}
SFC	1019.42	13.94	291.40	8.07	12.24	1.17	1218.81	141.24
1 KM	905.75	11.43	285.98	8.07	7.12	1.17	1103.43	120.16
2 KM	803.48	9.60	282.30	10.61	4.01	1.17	991.65	130.99
3 KM	711.30	8.43	277.70	17.21	2.20	.55	892.21	177.65
4 KM	627.31	9.10	272.50	15.52	1.40	.27	802.04	134.50
5 KM	552.73	9.70	267.11	12.85	.80	.10	720.88	93.65
6 KM	486.66	9.87	261.41	11.47	.48	.04	648.64	70.60
7 KM	426.27	9.35	254.10	14.25	.29	.02	584.49	75.42
8 KM	371.97	8.71	246.79	17.35	.18	.01	525.13	78.57
9 KM	323.36	8.00	239.49	20.76	.11	0.00	470.36	80.09
10 KM	279.84	7.12	232.68	19.46	.06	0.00	418.97	63.10
11 KM	241.13	6.15	226.37	13.57	.04	0.00	371.08	36.46
12 KM	207.02	5.26	220.16	8.74	.02	0.00	327.60	19.35
13 KM	176.71	3.66	216.80	7.43	.01	0.00	283.97	12.73
14 KM	150.79	2.40	214.14	6.89	.01	0.00	245.31	9.03
15 KM	128.47	1.55	211.48	6.37	.01	0.00	211.63	6.38
16 KM	109.15	.99	208.82	5.88	0.00	0.00	182.13	4.46
17 KM	92.33	.62	208.50	5.20	0.00	0.00	154.30	2.84
18 KM	78.51	.39	210.73	4.36	0.00	0.00	129.72	1.65
19 KM	66.80	.25	212.88	3.59	0.00	0.00	109.27	.94
20 KM	56.90	.15	215.11	2.90	0.00	0.00	92.23	.54
21 KM	48.70	.12	217.15	2.34	0.00	0.00	78.02	.30
22 KM	41.60	.24	218.86	2.13	0.00	0.00	66.21	.20
23 KM	35.60	.34	220.56	1.93	0.00	0.00	56.21	.13
24 KM	30.50	.40	222.27	1.73	0.00	0.00	47.80	.08
25 KM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

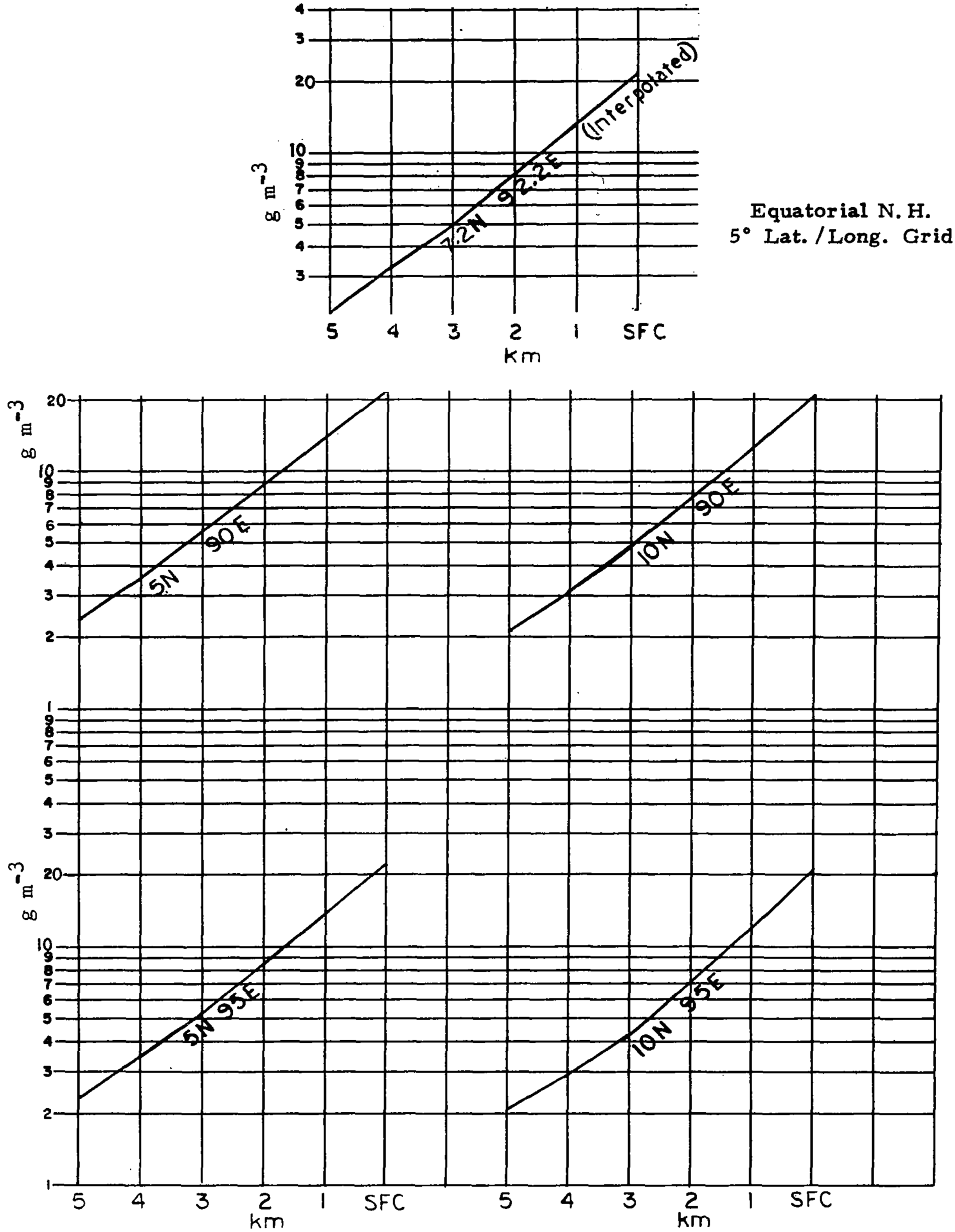


Figure 14. Example of Interpolated Moisture Profile and Profiles at 4 Surrounding Points

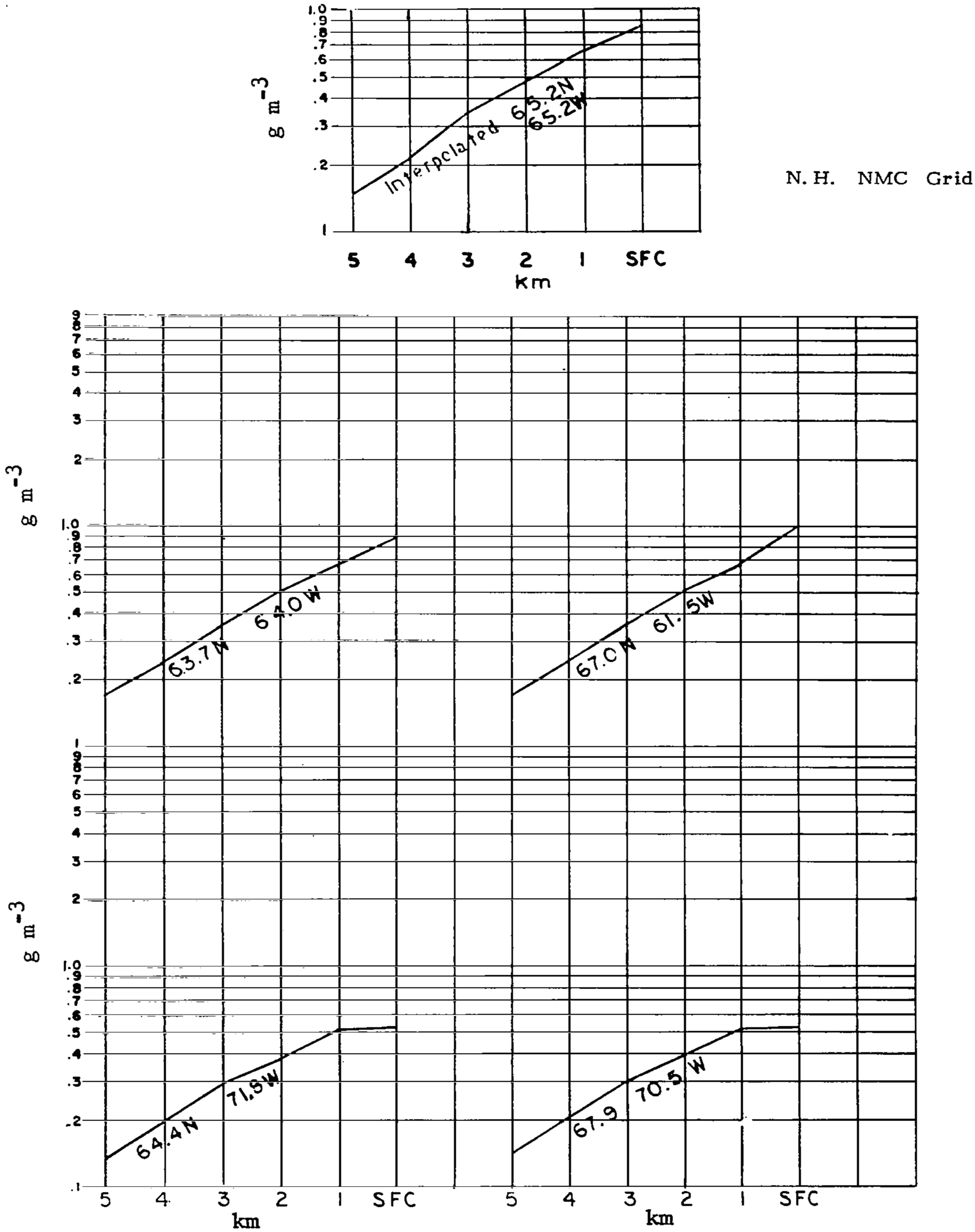
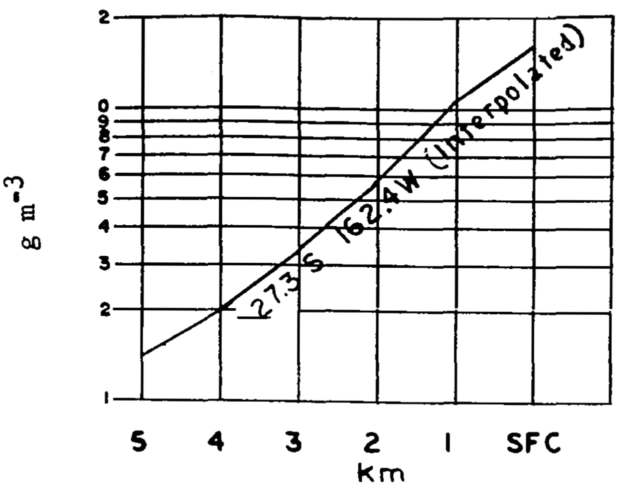


Figure 15. Example of Interpolated Moisture Profile and Profiles at 4 Surrounding Points



S. H. - 5° Lat./Long. **Grid**

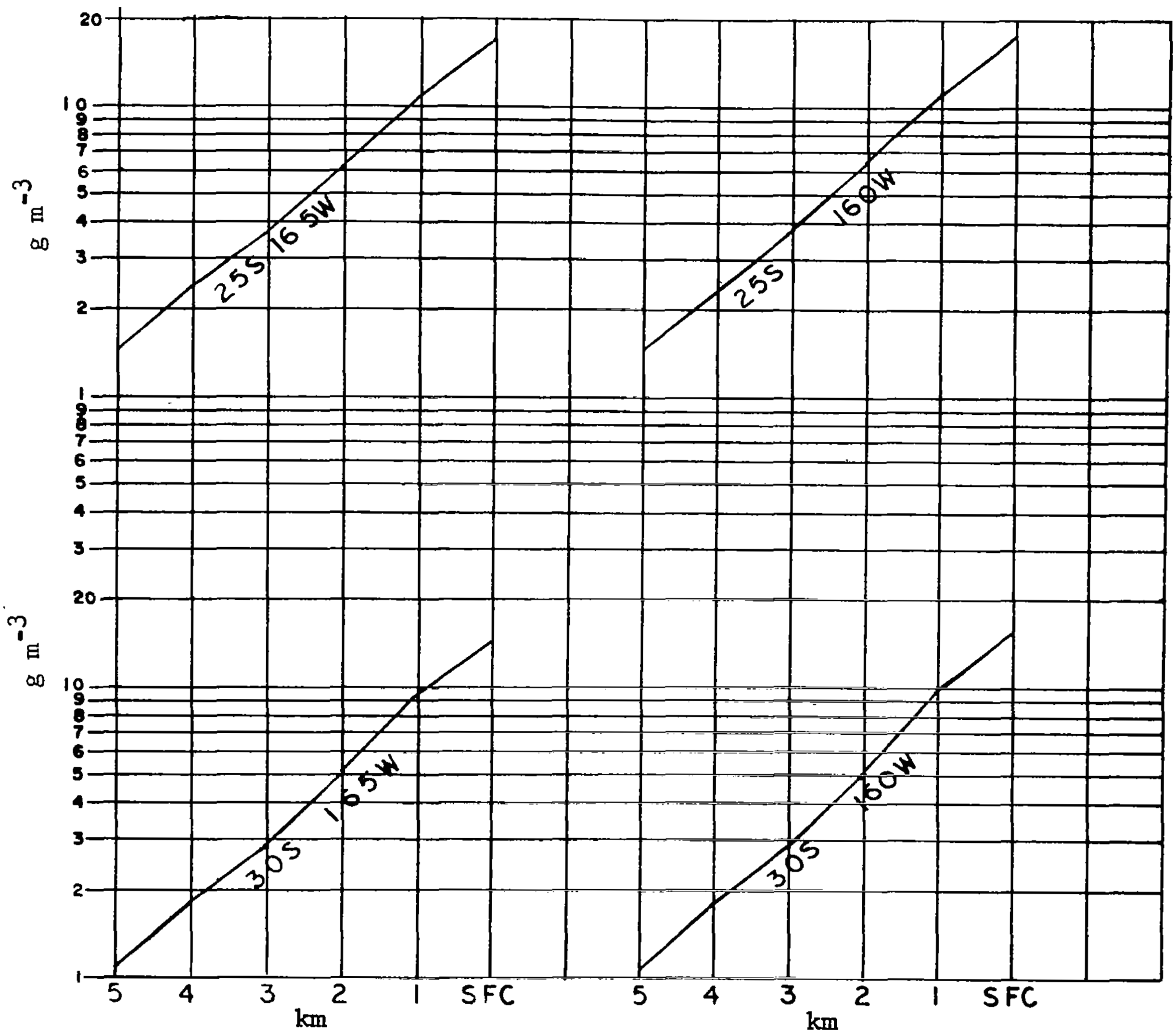


Figure 16. Example of Interpolated of Moisture Profile and Profiles at 4 Surrounding Points

4. MISSION SIMULATION PROCEDURES

While it is well known that electromagnetic sensors are affected by atmospheric properties, particularly moisture, complete attenuation models combining the effects of moisture, temperature, and density are still in the planning stage of development. The ultimate use of the 4-D atmospheric models will be as input to the complete attenuation models that will be able to predict the degree of electromagnetic sensor degradation anticipated for any earth resources mission. The design of mission simulation procedures, however, does not necessarily require the availability of a complete attenuation model for all wavelengths. For a number of spectral intervals, the gaseous component of the clear atmosphere which attenuates significantly is water vapor.

Relationships between precipitable water and the degree of atmospheric opacity (due to water vapor alone) for selected microwave frequencies are well known. Gaut and Reifenstein (1971) have used these relationships to calculate the opacity of the atmosphere in decibels (db) as a function of frequency for various values of precipitable water. These values were used in this study to demonstrate the proposed simulation procedure.

Users of earth resources data may frame questions regarding atmospheric attenuation in a number of ways. One question might be: "What is the frequency of various categories of atmospheric opacity (due to water vapor) for a particular month for selected wavelengths at specified locations along a satellite track?" A second question could be: "How many days are required (for a satellite track over a particular region(s) to achieve an acceptable degree of opacity for selected wavelengths at particular points along the satellite track?" For this question, "Acceptable opacity levels" must be defined for each frequency. The answers to these questions are dependent on the statistics of precipitable water in combination with the 4-D model data. However, as mentioned at the beginning of this section, complete reliable attenuation models incorporating effects of atmospheric temperature and density are under development. The remainder of the discussion of mission simulation will consider only the effect of moisture, recognizing that the 4-D profile data when used with complete attenuation models will improve the attenuation calculation.

The precipitable water data was processed in a manner that allows one to develop procedures to answer questions similar to those posed above. Daily precipitable water values for 69 stations in the United States (representing 13 homogeneous moisture regions) were made available on magnetic tape by the National Weather Service. The data consists of 8 years of twice daily data observations for each station. To answer the first question, regarding frequency of various categories of atmospheric opacity, the frequency distributions of precipitable water in specified categories (averaged for each day) were computed for all stations for each month of the year. Ten categories of precipitable water amount were defined (.5gm cm^{-2} intervals from 0 to 4 gm cm^{-2}, 4 to 5 gm cm^{-2}, and greater than 5 gm cm^{-2}). For each month, the 69 stations were grouped by homogeneous region and the average frequency distributions for the regions were computed. (Refer to Figure 1 for homogeneous regions in the United States). Figures 17 through 29 depict the regional frequency distributions for precipitable water categories for mid-season months. One can determine the zenith atmosphere opacities that correspond to the precipitable water values bounding each category using the relationships described in Gaut and Reifenstein (1971). Table 7 is an example of the conversions from precipitable water amounts to opacities for selected microwave frequencies. Thus, the precipitable water categories in Figures 17 through 29 may be relabeled in terms of categories of opacity (db) for any desired microwave frequency. (Those frequencies given in Table 7 are either near-resonant frequencies or near-minimums between the resonant frequencies.)

The distributions in Figures 17 through 29 may be thought of as unconditional probability distributions and as such may be useful in planning for earth resources technology satellite (ERTS) experiments.

An analysis of the mean moisture profiles for the 13 homogeneous regions in the United States was made for all seasons and compared in detail with the moisture distributions for the remaining 32 homogeneous regions over the globe. The objective of this analysis was to determine which known (regional) frequency distributions of precipitable water could be applied as being representative of the unknown regional distributions. Table 8 provides the results of the detailed comparative analysis. The necessary assumption is that mean monthly moisture profiles are related to mean monthly distributions of precipitable water and this is believed to be a reasonable assumption.

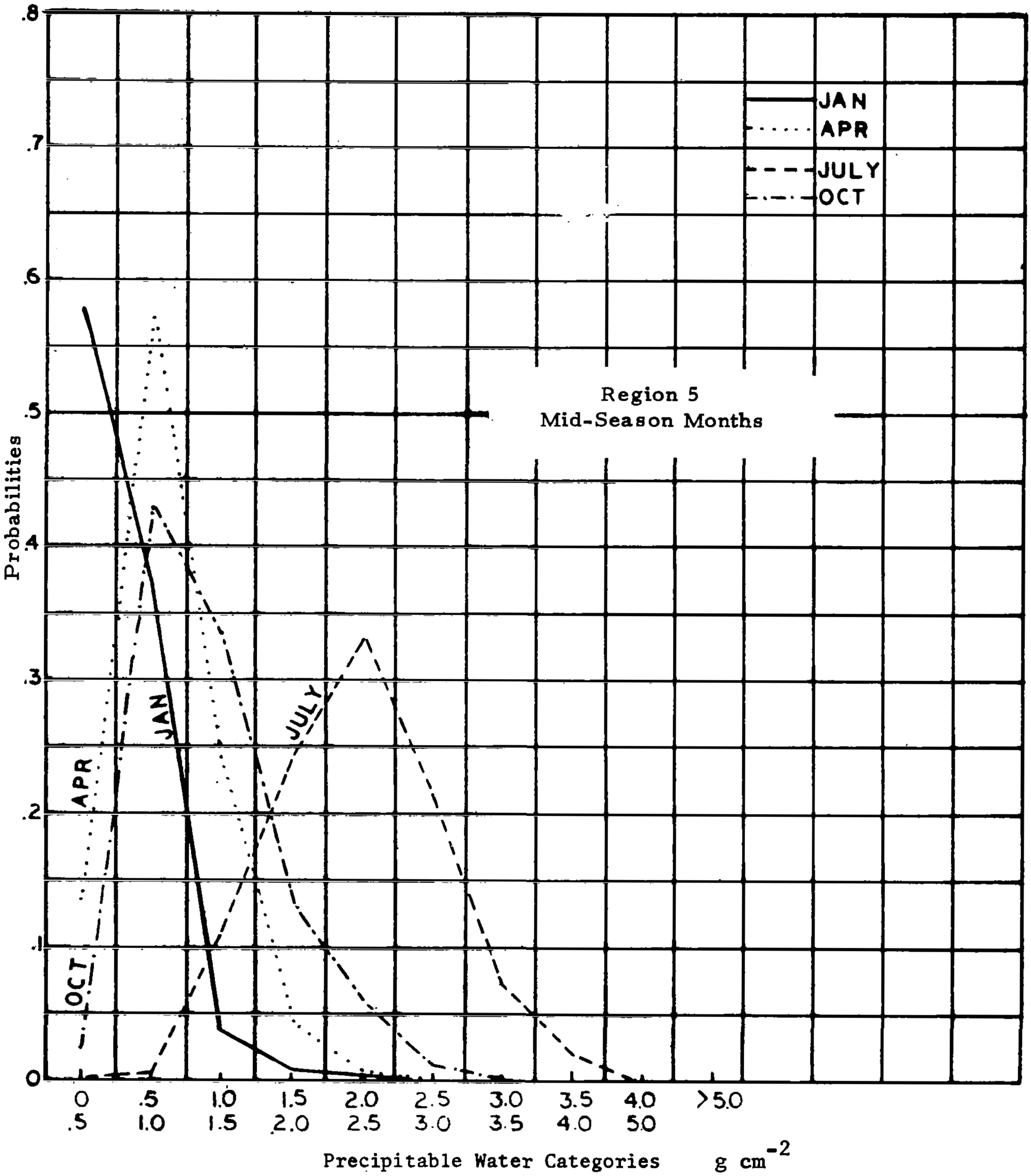


Figure 17. Mean Frequencies of Precipitable Water

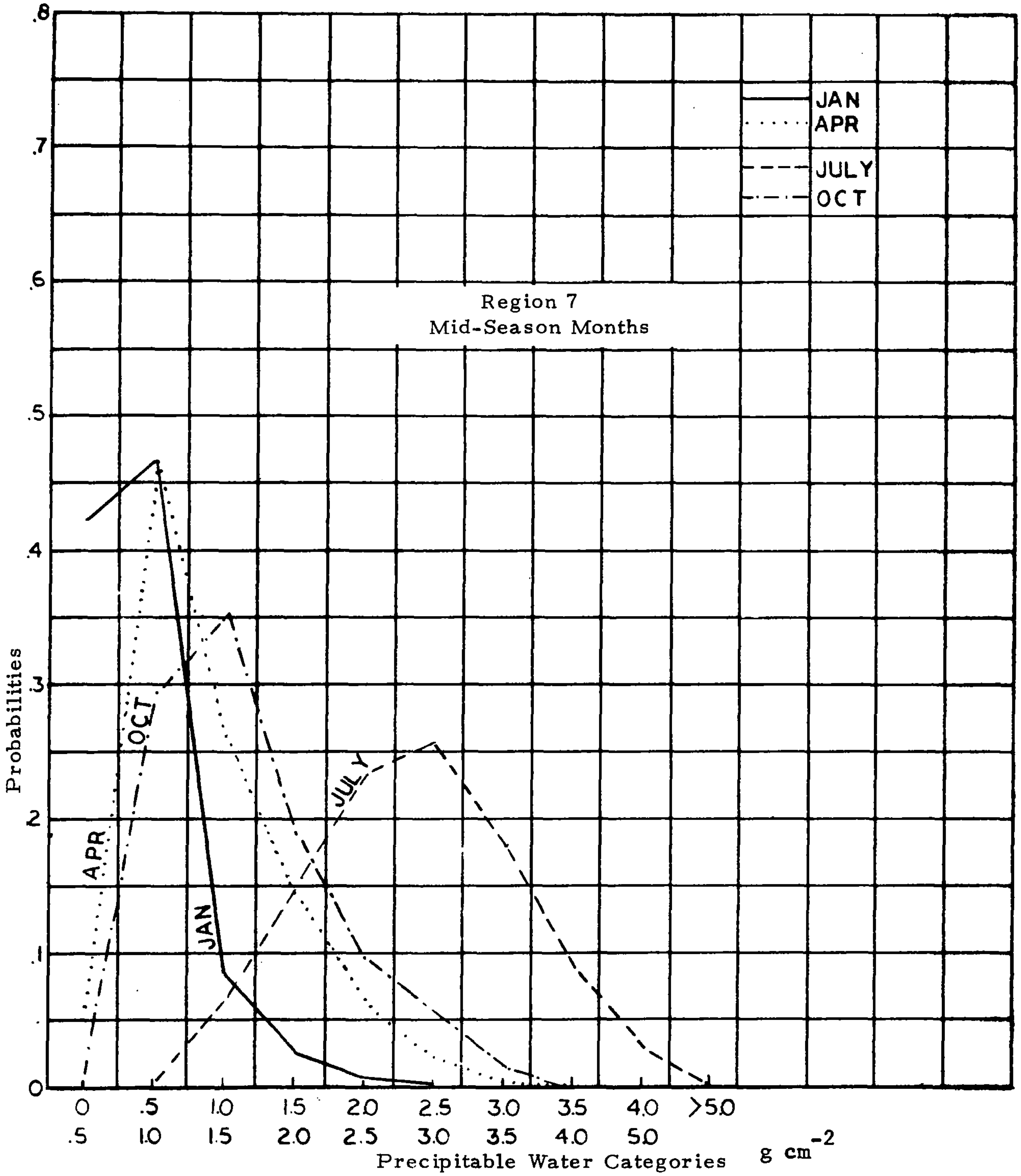


Figure 18. Mean Frequencies of Precipitable Water

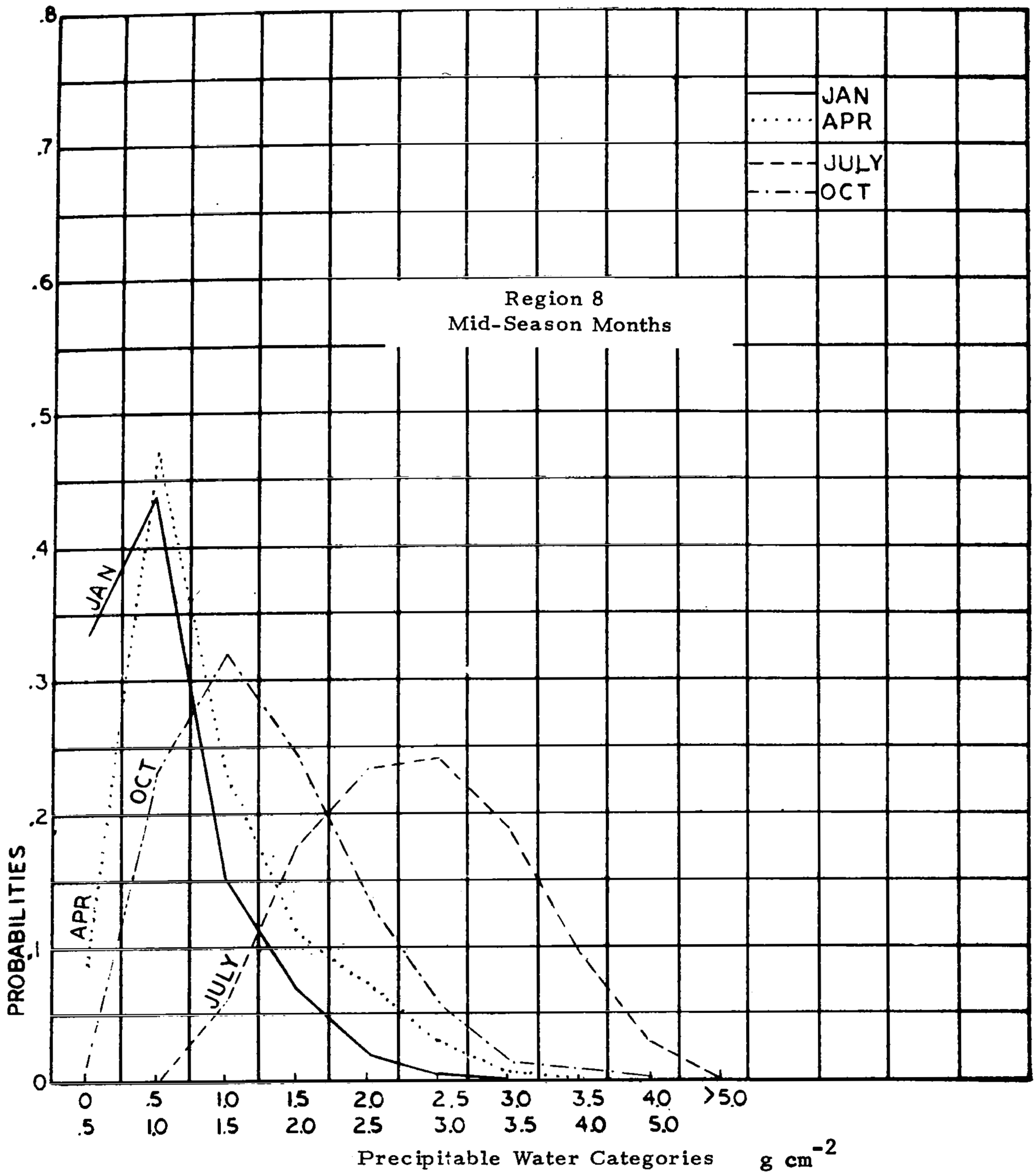


Figure 19. Mean Frequencies of Precipitable Water

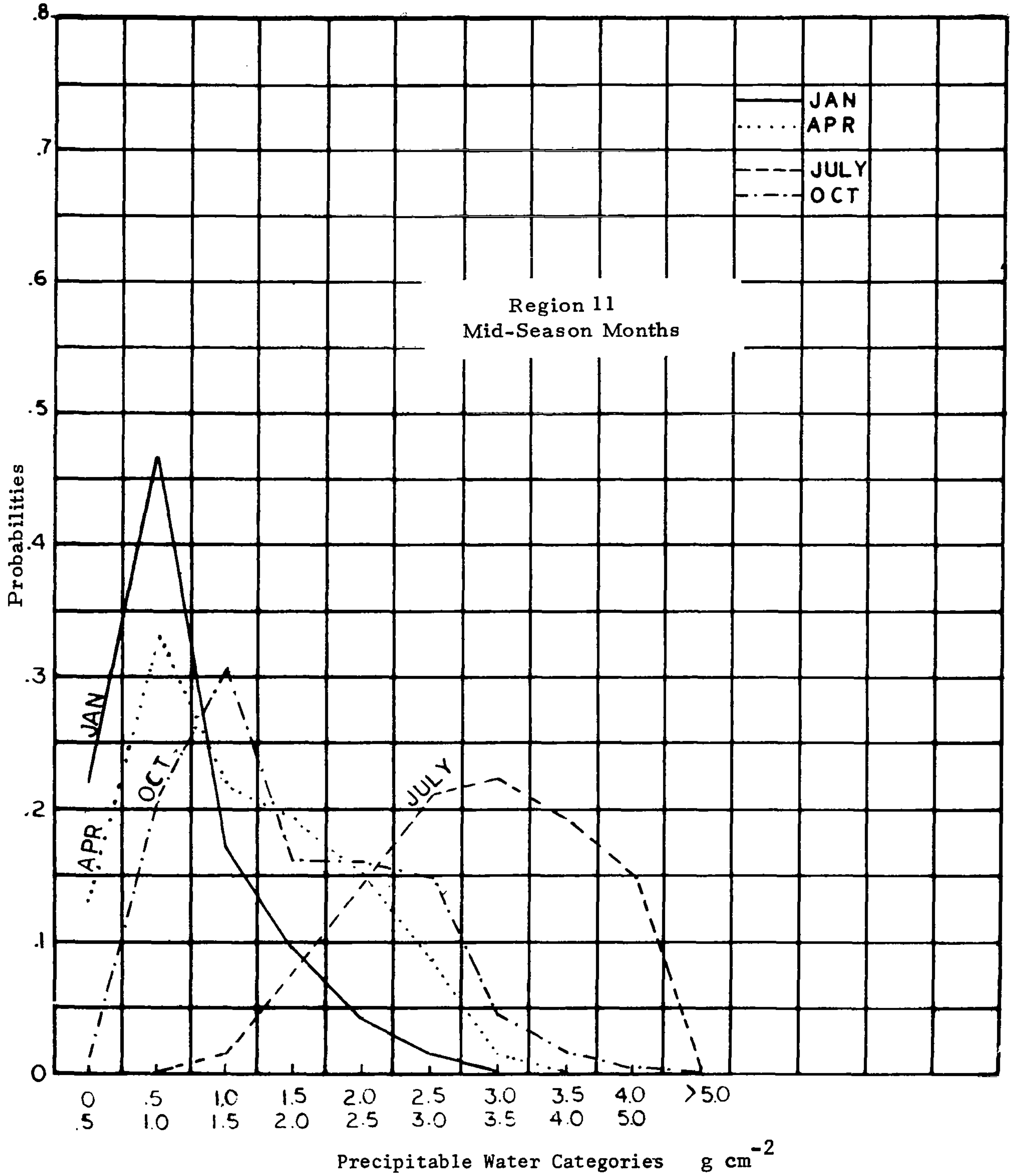


Figure 20. Mean Frequencies of Precipitable Water

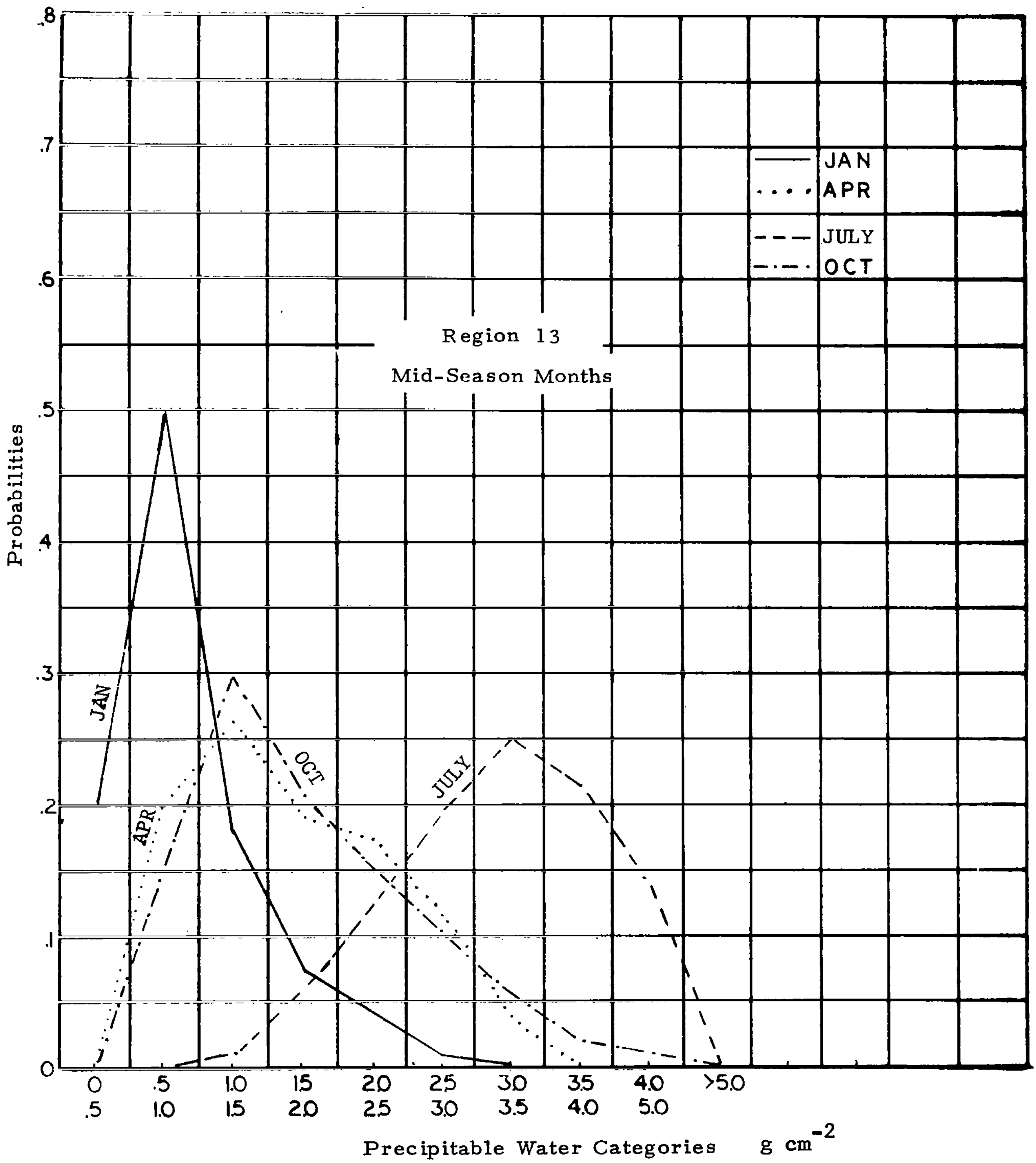


Figure 21. Mean Frequencies of Precipitable Water

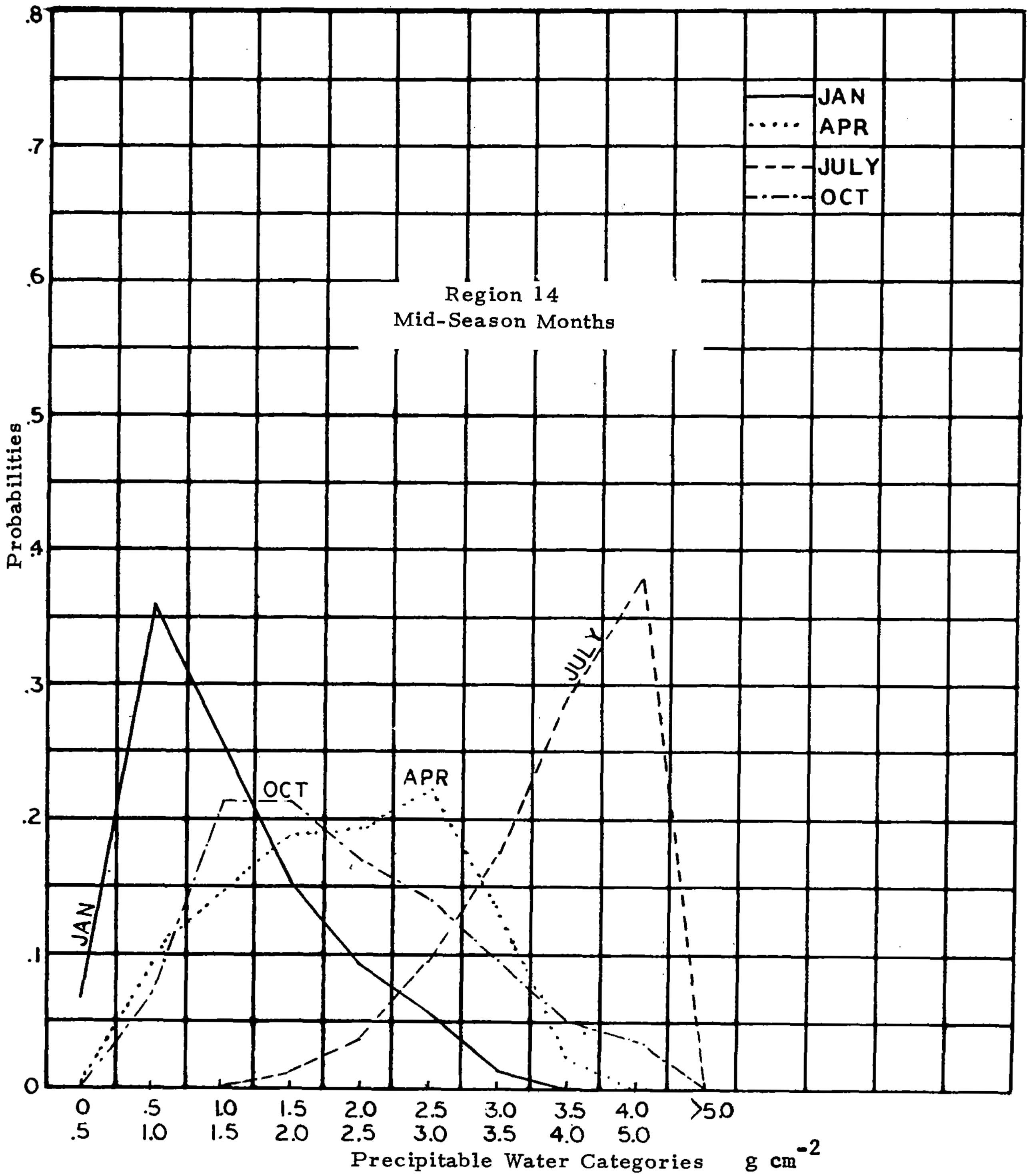


Figure 22. Mean Frequencies of Precipitable Water

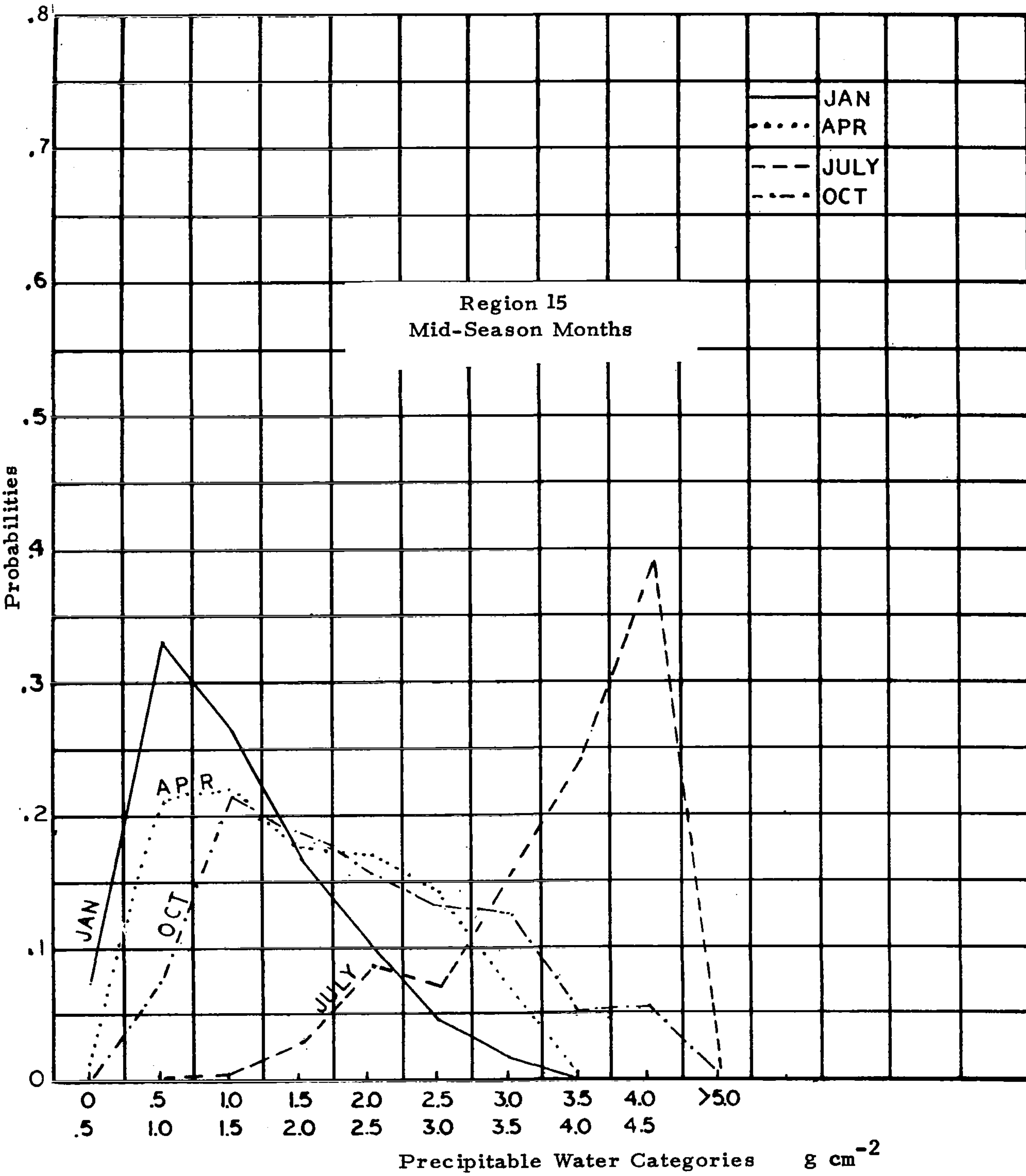


Figure 23. Mean Frequencies of Precipitable Water

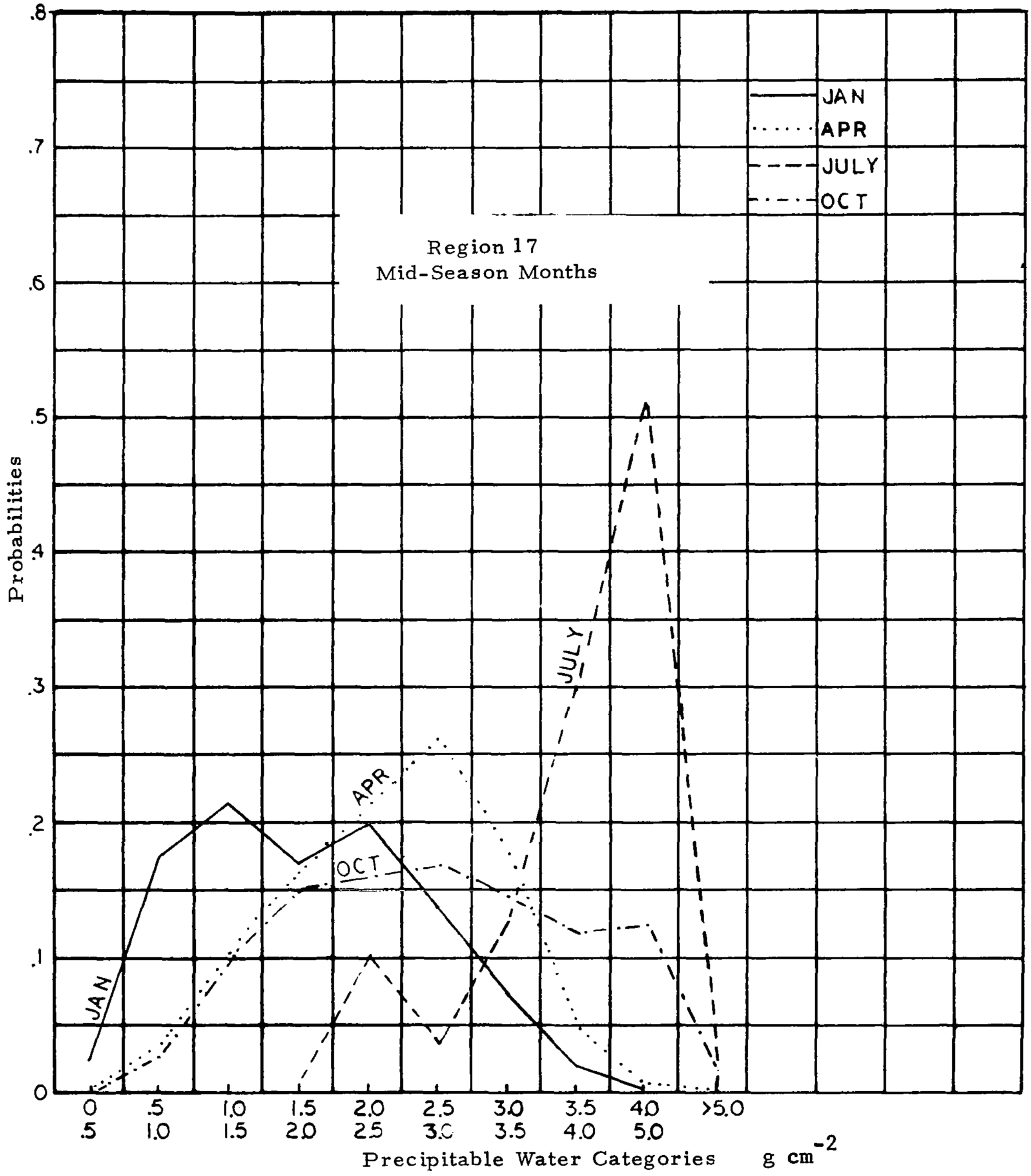


Figure 24. Mean Frequencies of Precipitable Water

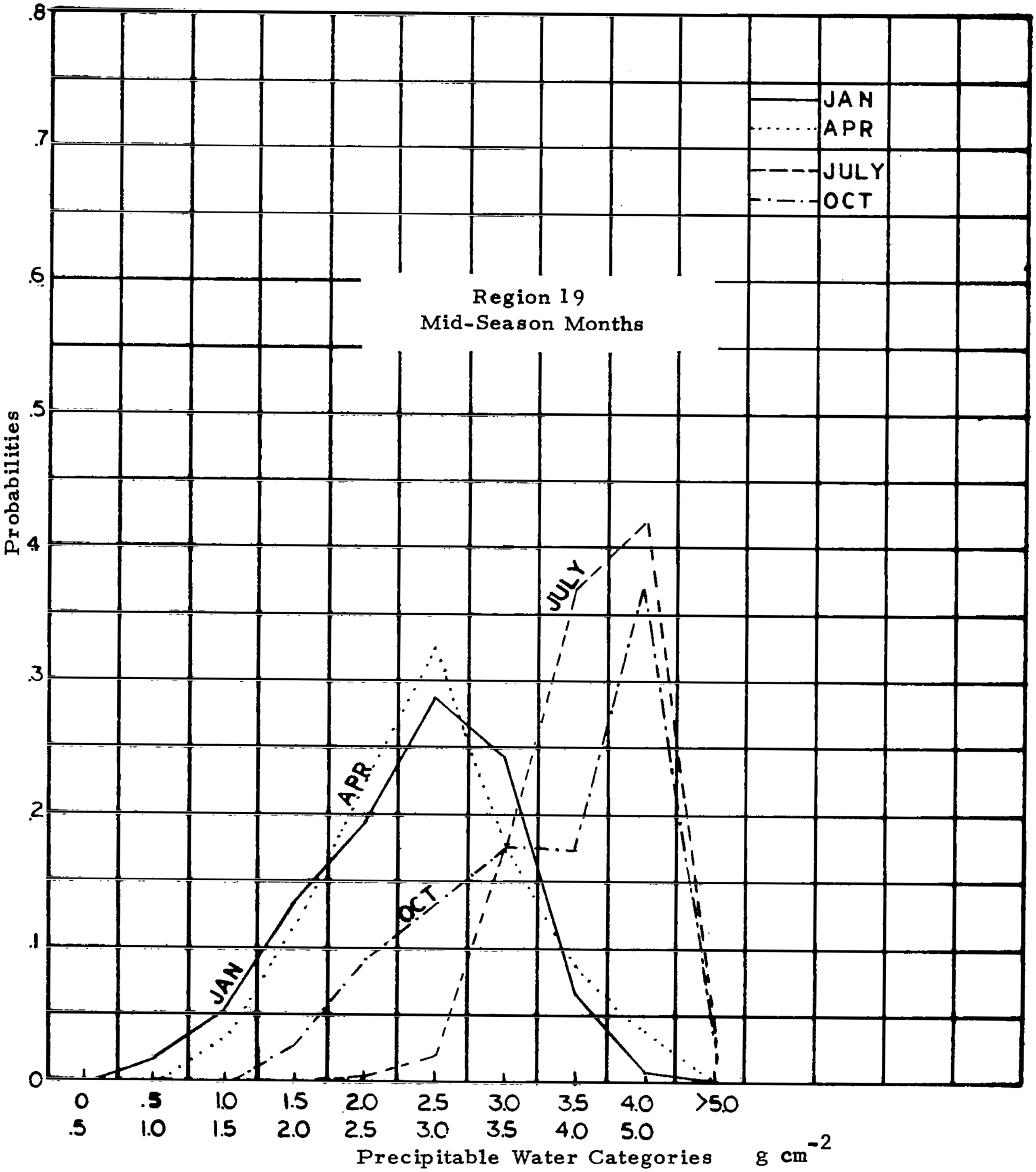


Figure 25. Mean Frequencies of Precipitable Water

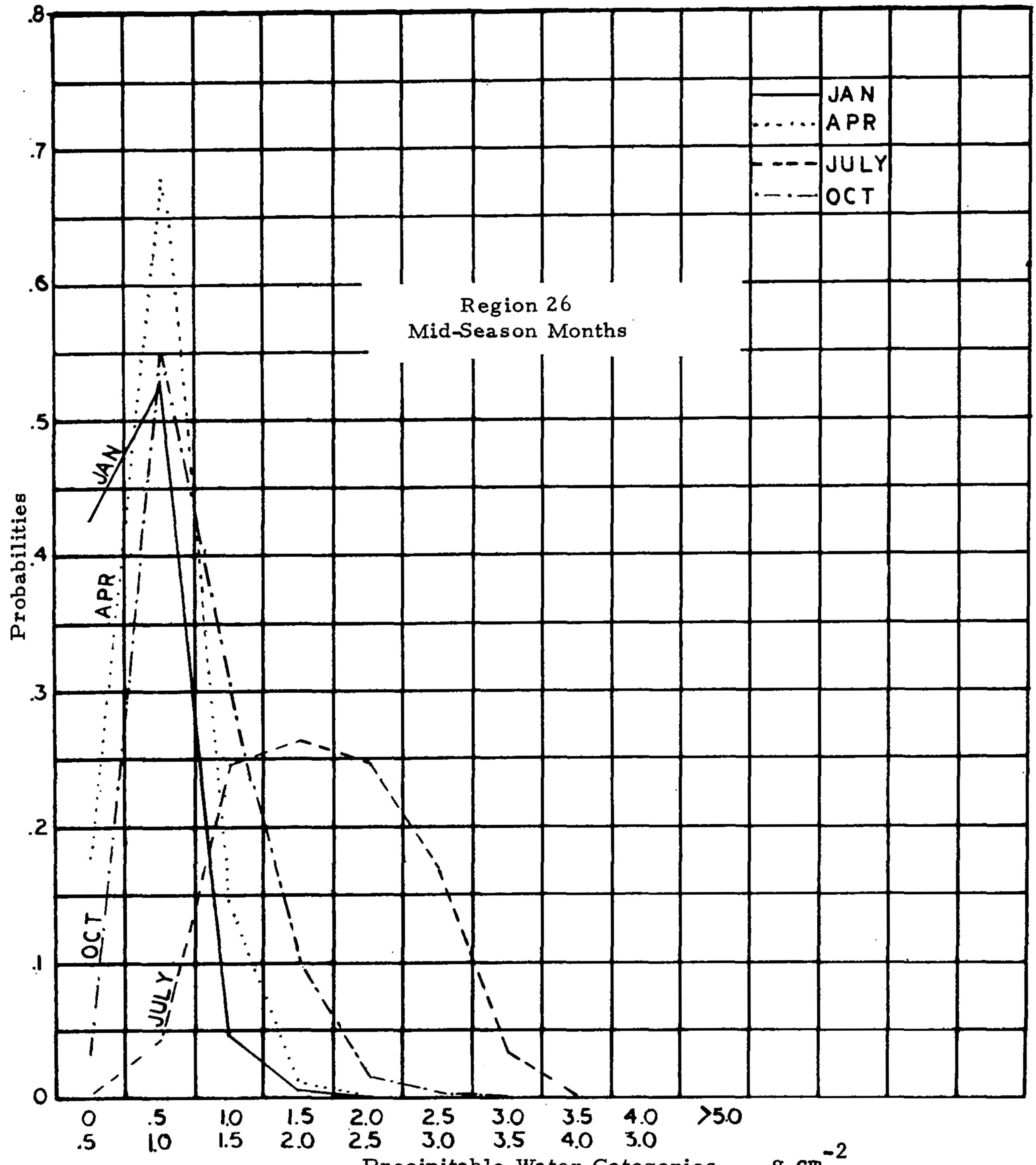


Figure 26. Mean Frequencies of Precipitable Water

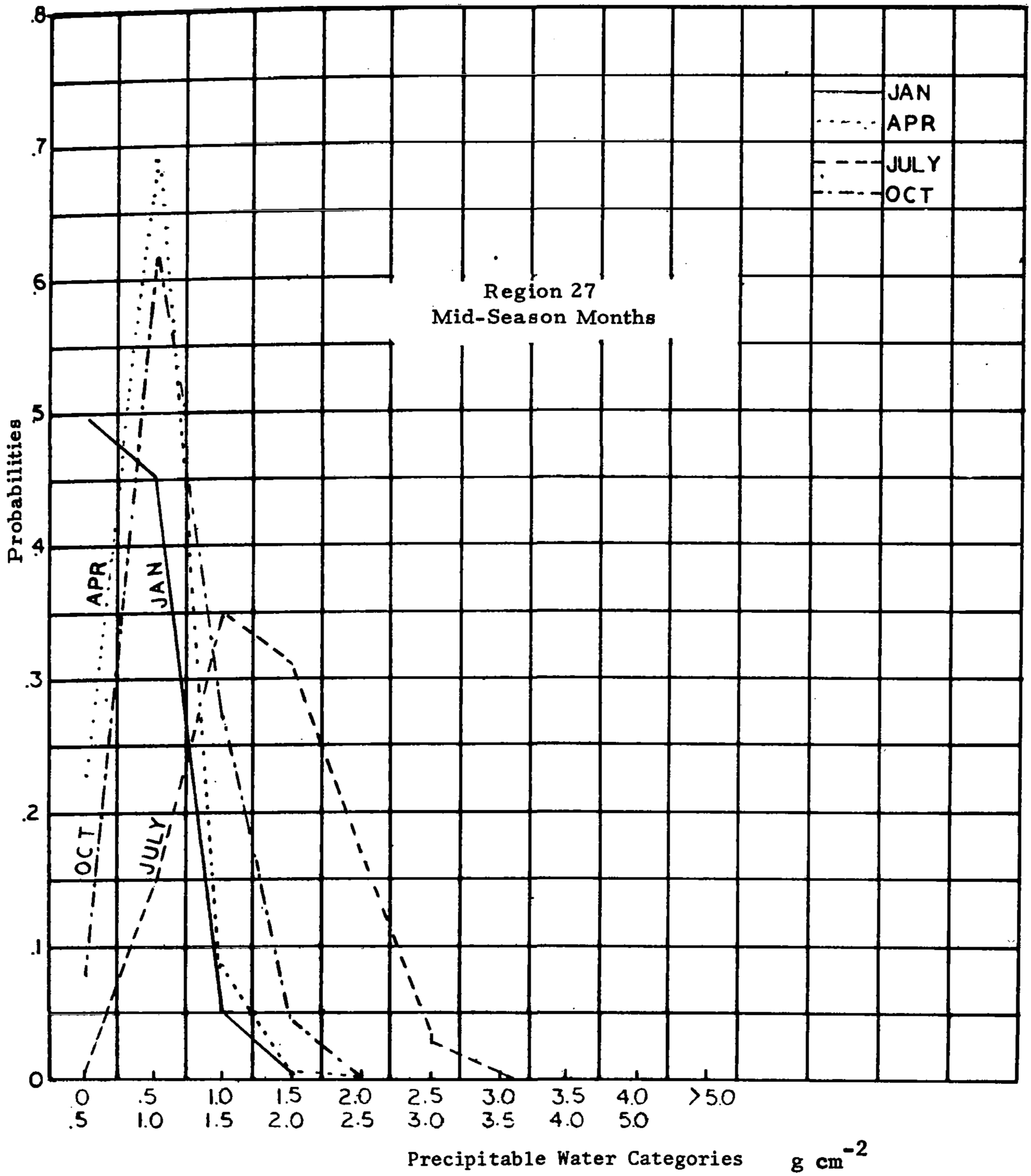


Figure 27. Mean Frequencies of Precipitable Water

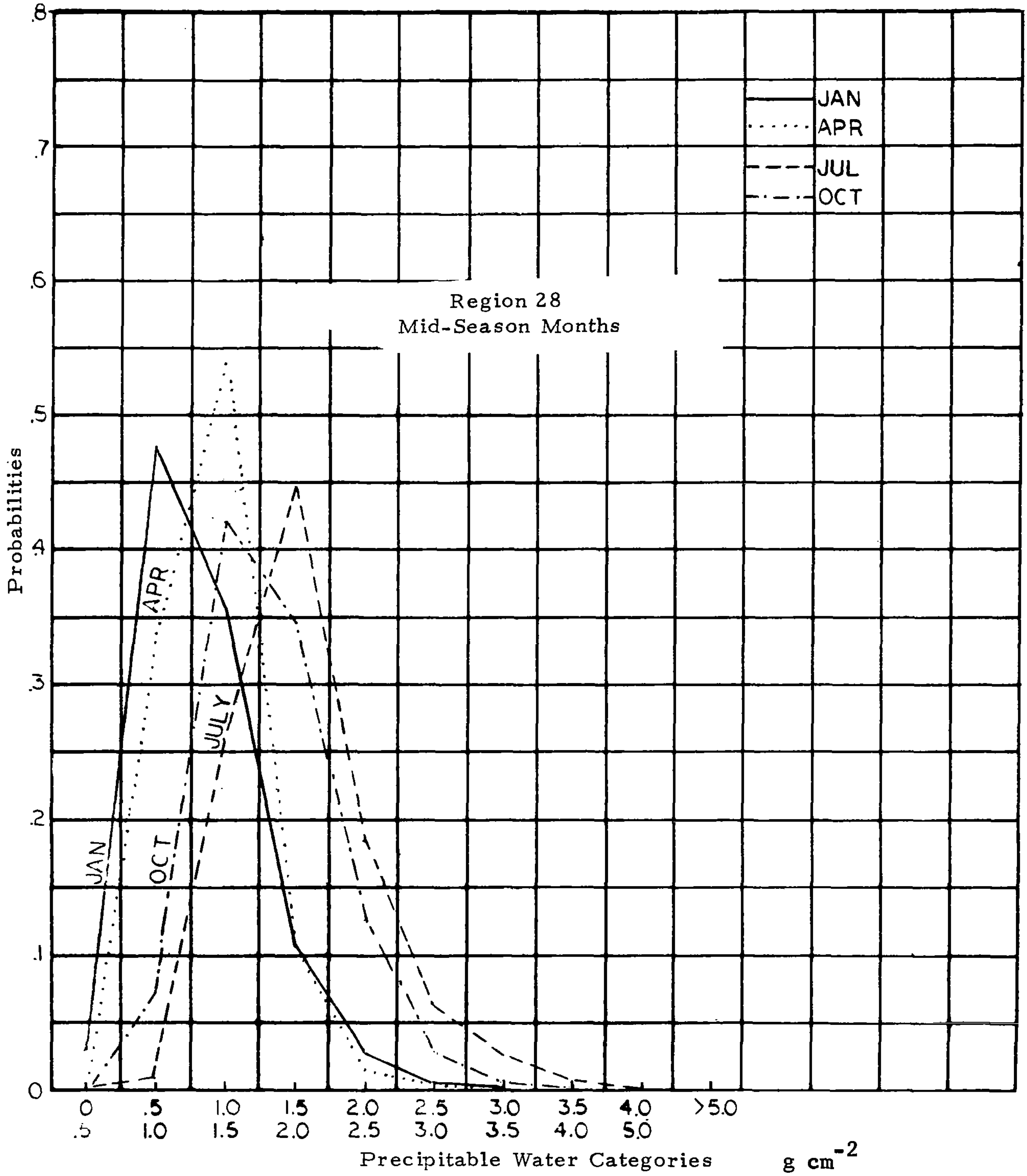


Figure 28. Mean Frequencies of Precipitable Water

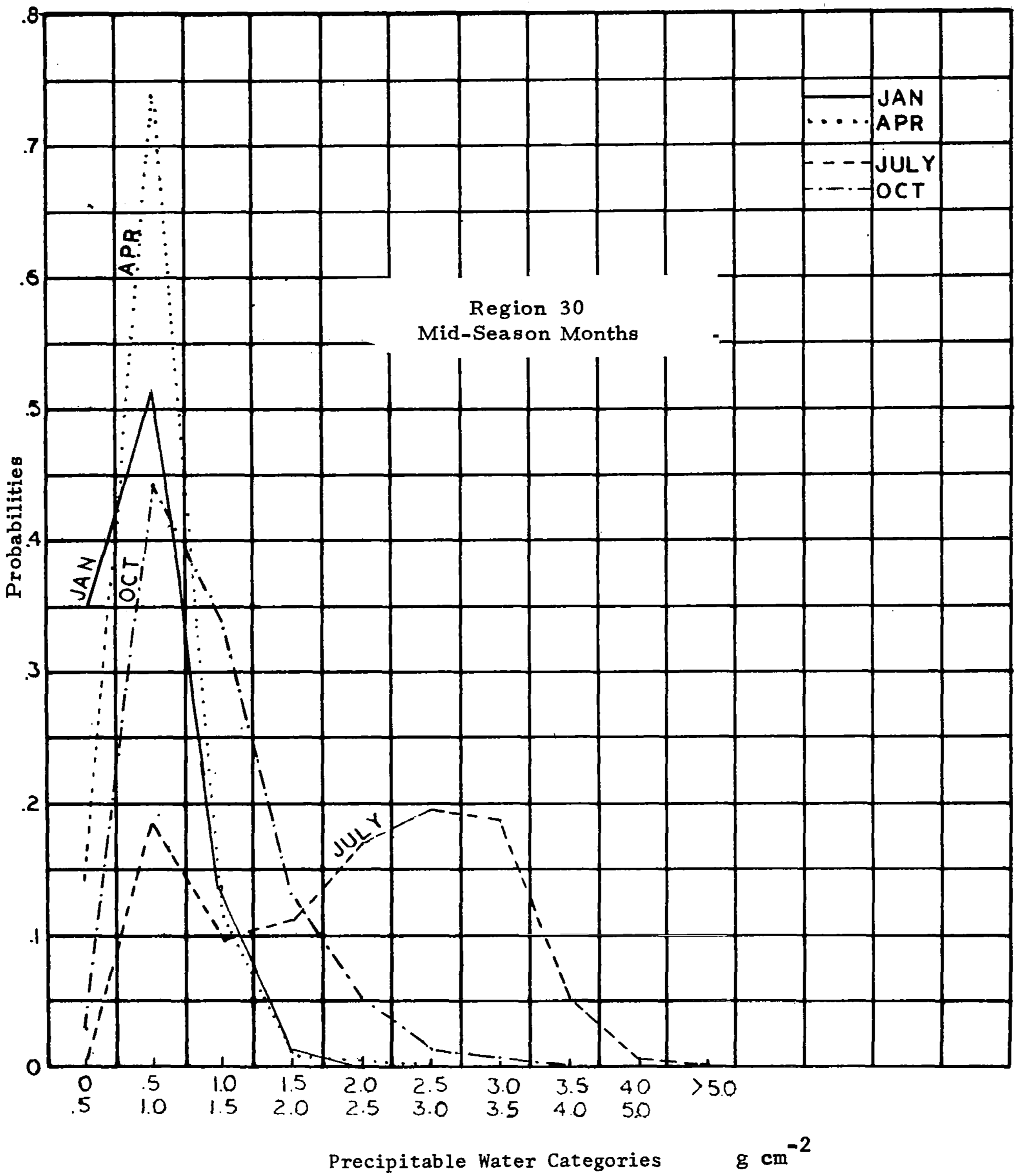


Figure 29. Mean Frequencies of Precipitable Water

TABLE 7

ZENITH OPACITY (db) FOR VALUES OF PRECIPITABLE WATER FOR SELECTED MICROWAVE FREQUENCIES

GHz / Pw $g\ cm^{-2}$	12	22	32	97	182	222	322
0	0	0	0	0	0	0	0
.15	.0012	.025	.006	.042	2.65	.28	3.2
0.5	.0056	.13	.032	.27	18.0	14.5	23.0
1.0	.013	.30	.066	.50	48.0	29.0	55.0
1.5	.023	.42	.110	.80	64.0	45.0	74.0
2.0	.033	.54	.16	1.15	78.0	58.0	89.0
2.5	.043	.57	.19	1.45	95.0	72.0	110.0
3.0	.053	.80	.23	1.75	120.0	87.0	135.0
3.5	.062	.93	.28	2.00	143.0	106.0	160.0
4.0	.070	1.08	.31	2.30	168.0	125.0	185.0
5.0	.078	1.32	.38	2.90	215.0	160.0	265.0

TABLE 8

SPECIFICATION OF APPROPRIATE REPRESENTATIVE REGIONAL AND SEASONAL FREQUENCY DISTRIBUTION OF PRECIPITABLE WATER FOR REGIONS WHERE DAILY PRECIPITABLE WATER DATA WERE UNAVAILABLE

Region Where Data Unavailable	Season			
	Winter	Spring	Summer	Fall
1	5-W Higher probability P.W. in first category.	5-W	5-SP	5-W
2	5-W Slightly higher probability for P.W. in first category	5-SP	5-F	5-SP
3	8-SP	5-SP Slightly higher probabilities in first two categories. P.W.	8-F	8-W
4	5-W Slightly higher probabilities in first two categories.	5-SP Slightly higher probabilities in first two categories.	5-S	5-F
6	7-W Slightly lower probabilities in first two categories.	7-SP Slightly lower probabilities in first two categories.	7-F	5-F
9	8-W Slightly higher probabilities in first two categories	8-SP	8-S	7-F
10	11-F	11-SP	11-S	11-F
12	8-F	8-F	15-F	17-F
16	17-W	17-W	15-S	19-W
18	19-W Higher probabilities in lower five categories	19-W	17-F	19-F
20	19-SP	19-SP	19-F	17-S
21	19-SP	19-SP	19-S	17-S
22	17-S	19-S	19-S 19-S Higher probabilities in highest three categories	
23	15-SP	15-F	13-S	19-W
24	19-S	19-S	19-S 19-S Higher probabilities in highest three categories.	
25	19-F	19-S	19-S 19-S Higher P.W. probabilities in highest three categories.	
29	17-W	15-S	19-S	17-S
31	5-F	8-SP	5-S	8-F
32	13-W	7-SP	8-S	14-SP
33	13-SP	14-F	17-S	15-F
34	7-W Lower probability in lowest P.W. category	14-F	19-S Higher probabilities in highest three categories	15-F
35	19-W	17-F	19-S	17-S
36	14-F	19-S	19-S 19-F Higher probabilities in highest three categories.	
Seasonal reversal between hemispheres accounted for; e.g. winter (June, Jly., Aug.)				
37	5-W Higher probability in lowest category	5-W	5-SP	5-W
38	5-W Higher probability in lowest category	5-SP Lower probability in lowest category	7-W	5-SP
39	5-F 5-F Higher probability in lower categories		8-SP	7-SP
40	5-F	5-F	7-F	7-SP
41	15-W Lower probabilities in lowest categories	15-SP	19-W	17-W
42	7-SP	5-S Exclude sfc	14-S Exclude sfc	14-F Exclude sfc
43	5-F	5-F	30-SP Slightly lower probabilities in lower categories	8-SP
44	8-W Slightly lower probabilities in lowest categories	8-SP	5-S	8-F
45	5-F	7-F	19-W	13-F

Numbers in table refer to regions where daily precipitable water data are available.

W = Winter
SP = Spring
F = Fall
PW = Precipitable Water

Adjustments (if any) are indicated in table. However, higher (lower) probabilities in one category necessarily require lower (higher) probabilities in other categories.

Slightly higher (lower) refers to adjustment of about 10%.
Higher (lower) refers to adjustment of about 20%.

The capability that provides mean atmospheric profiles and daily variances for any point(s) and month(s) (from the program developed as discussed in Section 3) when used as input to attenuation models and combined with the probability distributions of atmospheric opacity for homogeneous moisture regions will allow mission planners to simulate various missions (i. e., select points along a satellite track for a particular month) and determine the expected atmospheric attenuation for any month of the year.

The concept of Monte Carlo techniques for mission simulations was put forward in studies on global cloud cover (Sherr et al, 1968; Greaves et al, 1971; Chang and Willand, 1972). In the first of these studies, the questions to be answered were "What is the probability of success for sighting a series of landmarks?" and "What is the mean number of successes in a specified number of trials (passes)?" In this study it was demonstrated that despite the fact that the probability distributions of successful landmark sightings approximated that of the binominal distribution, the use of the Monte Carlo technique gave answers considered more realistic than those given by the simpler binominal probability distributions.

The problem of the expected atmospheric attenuation over specific regions and the probability that an ERTS satellite will successfully "sense" what is desired for a particular mission is analogous to the landmark sighting problem.

Unconditional probability distributions of various precipitable water categories, which may be converted to atmospheric opacity categories for different microwave frequencies, lend themselves to the use of a Monte Carlo technique for mission simulations that can help answer the second question that may be asked by ERTS planners concerning the number of trials (days) required to achieve "acceptable degree of opacity" for given missions. Therefore it is recommended that a Monte Carlo procedure be used with the precipitable water frequency distributions for the various homogeneous moisture regions to determine the number of days required for a given mission providing the information desired.

The concept of the computer program for mission simulation is similar to that for the cloud cover. Because only unconditional distributions of precipitable water (atmospheric opacity) will be used, the program could be simpler (no conditional distributions have been generated in this study, although it would be possible to derive temporal conditional tables with the available data). However, in another respect, the program may be somewhat more complex in that a greater number of categories of opacity are required than was the case for cloud cover and that the opacity levels differ for different frequencies.

The actual simulation program itself can be written when information becomes available on the requirements for various experiments that will use the electromagnetic sensors.

5. FEASIBILITY OF COMBINING TECHNIQUES FOR 4-D MODELS AND CLOUD COVER

The four-dimensional atmospheric models when used as input to the attenuation models will provide information on the expected signal attenuation due to the atmosphere - in the absence of clouds. The global cloud statistics for computer simulations, Sherr et al (1968), Greaves et al (1971), and Chang and Willand (1972) generate the cloud cover, cloud layers and cloud type given the location and month of the year.

In considering the feasibility of combining the 4-D and cloud models, the major questions are: should the computer programs be combined into one larger computer program? and, should the data that comprise the input to the models be meshed onto one set of tapes? The alternatives are to keep the programs and data as separate entities but provide for a link between the two models to enable the output of one to be part of the input to the second model.

The factors involved in deciding the approach to take, are:

- The degree of complexity involved in the program design.
- The efficiency of a combined model as opposed to the efficiency of separate models run back to back.
- The core storage limits of the computer system.

Evaluation of these factors has led to the conclusion that the programs can and should be linked together with the data remaining on separate sets of tapes.

The cloud mission simulation techniques are a function of homogeneous cloud regions and these are different from the homogeneous moisture regions. For a given mission simulation, the cloud model should be run first, because if the cloud statistics indicate that the mission will be a "failure" (criteria for success or failure is part of the input to the program), there should be the option to automatically eliminate that location from processing with the 4-D model data; i. e., a failure indicates that the clouds will cause unacceptable attenuation.

The attenuation due to atmospheric parameter profiles is a secondary effect and one may or may not want to determine its value in those areas where there is significant attenuation due to clouds.

It would be relatively simple to link the two programs by having the input to the locations required for the 4-D model mission simulations be based on the locations determined to be a "success" from the cloud model run. In the cases where the option to run the 4-D model mission simulation regardless of the outcome of the cloud model is selected, the test points for the 4-D model run will be identical to those specified for the cloud model.

To summarize, the recommendation is to link a global cloud model mission simulation program with a 4-D atmospheric model mission simulation program and have the cloud model program run first.

6. CONCLUSIONS AND RECOMMENDATIONS

Evaluation of the four-dimensional atmospheric models previously developed revealed that two significant refinements were required. In one case, significant differences in mean profiles were evident in identical northern and southern hemisphere homogeneous regions for nine of 36 regions. Nine "new" regions were added in the southern hemisphere to give regional profiles that are representative of the southern hemisphere alone (as opposed to the previous merger of northern and southern hemisphere data for the same regions and seasons). In another case, southern hemisphere moisture variances at individual points were discovered to have unrealistically high values at a number of points. A new technique to compute these moisture variances was developed and results are improved markedly.

A major accomplishment of this study was the development of a technique and a computer program than can generate mean monthly profiles and daily variances of moisture, temperature, pressure and density, for any point on the globe and any month of the year. This is believed to provide a unique capability that will be extremely useful to planners of earth resources space missions. These planners will be able to use the profiles at desired points as input to attenuation models that will provide information on expected atmospheric attenuation. Another potential use of the 4-D model atmospheres is in trajectory and vehicle heating analyses. In addition, because they can be used as reliable reference atmospheres for any location and month of the year, they may have important application in numerous studies by a number of government agencies.

For some purposes, such as feasibility studies and preliminary mission simulations, one may want to use the computer program that generates atmospheric profiles as a function of homogeneous region, because it is more economical to run.

Other significant results of this study are recommendations to (1) use a Monte Carlo procedure with the four-dimensional atmospheric models in computer mission simulations and (2) link the computer program for the 4-D models to the back of the cloud statistics model computer program to predict both cloud cover and signal attenuation.

On the basis of the results of this study, we would recommend that actual tests be performed to determine the value of the 4-D models in remote sensing data simulations, and that simulation procedures be developed to predict both cloud cover and signal attenuation for any area of the globe and time of the year.

In addition, the global atmospheric profile data should be extended to 55 km. Also, it may be of value to determine temporal conditional probabilities of precipitable water for use in mission simulation.

7. REFERENCES

Chang, D. T. and J. H. Willand, 1972: Further Developments in Cloud Statistics for Computer Simulations, Final Report, Contract No. NAS 8-26847, Allied Research Associates, Inc., Concord, Mass.

Crutcher, H. L. and J. M. Meserve, 1970: Selected Level Heights, Temperatures and Dew Points for the Northern Hemisphere, (NAVAIR 50-1C-52) Naval Weather Service Command.

Gaut, N. E. and E. C. Reifenstein, III; 1971: Interaction Model of Microwave Energy and Atmospheric Variables, NASA CR-61348, Environmental Research and Technology, Inc., Waltham, Mass. (Prepared for NASA-George C. Marshall Space Flight Center).

Greaves, J. R., D. B. Spiegler and J. H. Willand, 1971: Development of a Global Cloud Model for Simulating Earth-Viewing Space Missions, NASA CR - 61345, Allied Research Associates, Inc., Concord, Mass. (Prepared for NASA-George C. Marshall Space Flight Center, Alabama).

Jenne, R. L., 1970: The NMC Octagonal Grid (unpublished manuscript) National Center for Atmospheric Research, Boulder, Colorado.

Sherr, P. E., A. H. Glaser, J. C. Barnes and J. H. Willand, 1968: Worldwide Cloud Cover Distributions for Use in Computer Simulations, NASA CR-61226, Final Report, Contract No. NAS 8-21040, Allied Research Associates, Inc., Concord, Mass.

Spiegler, D. B. and J. R. Greaves, 1971: Development of Four-Dimensional Atmospheric Models (Worldwide), NASA CR-61362 Allied Research Associates, Inc., Concord, Mass.

NASA-Langley, 1972 —— 20 M196